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PROPERTIES OF CRYOGENICALLY WORKED MATERIALS

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MARTIN MARIETTA CORPORATION

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA Lewis Research Center

Contract NAS3-12028

James R. Faddoul, Project Manager

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INTERIM REPORT

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FOREWORD

The work described herein, which was conducted by the Martin Marietta Corporation, Denver Division, was performed under NASA Contract NAS3-12028. The work was done under the management of the NASA Project Manager, Mr. James R. Faddoul, Liquid Rocket Technology Branch, NASA-Lewis Research Center.

ABSTRACT

Fifteen metallic alloys were tested to determine whether straining (uniaxial tension) at cryogenic temperatures developed higher strengths than did straining at room temperature. Two alloys were significantly strengthened by cryostraining: PH 14-8 Mo, a precipitation hardening stainless steel; and MP 35 N, a nickel-cobalt alloy. Seven alloys: 6061, 5456, Inconel 718, Nickel 440, beryllium copper, A-286, and 21-6-9 could be strained greater amounts, thereby developing higher strengths, at cryogenic temperatures than at room temperature. For the other alloys, 2219, L-605, LA141A, TRIP steel, Ti 6Aℓ-4V ELI, and Ti 5Aℓ-2.5Sn ELI, straining at cryogenic temperatures was not beneficial.

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PROPERTIES OF CRYOGENICALLY WORKED MATERIALS

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SUMMARY

This is an Interim Report of the first year's work on the two-year program being conducted under Contract NAS3-12028. The objective of the program is to find a metallic alloy that can be significantly strengthened by cryoworking and yet retain sufficient toughness, corrosion resistance, and other essential characteristics so that its usefulness as a structural material is not lost.

During the first year of the program 15 selected alloys were subjected to a series of tests designed to identify those alloys that were most significantly strengthened by cryoworking. The second year's effort will consist of a more detailed investigation of a limited number of alloys that, from the previous testing, are known to have a high potential for developing higher strengths through cryoworking. Specifically these alloys will be tested to determine how uniaxial straining at a cryogenic temperature affects their room temperature tensile properties; fracture toughness characteristics; and stress corrosion resistance. Also, tests will be conducted to determine how thermal treatment (aging) response is affected by prior cryostraining.

The first year's effort reported herein, consisted of five basic tasks, namely:

Task I - Material Selection and Procurement;

Task II - Preparation of Baseline and Cryosoaked Specimens;

Task III - Preparation of Cryoworked Specimens;

Task IV - Room Temperature Testing;

Task V - Evaluation of Results.

During Task I, applicable data, identified through various literature searches, were reviewed, and cognizant personnel in the metal working industry were contacted to obtain the information needed to select the 15 alloys to be tested. Ultimately, the following alloys were tested:

2219 aluminum alloy;

5456 aluminum alloy;

6061 aluminum alloy;

Beryllium copper;

L-605 cobalt alloy;

MP 35 N cobalt-nickel alloy;

LA141A magnesium alloy;

Inconel 718 nickel alloy;

Nickel 440 nickel alloy;

A-286 austenitic precipitation hardening corrosion resistant steel;

PH 14-8 Mo semiaustenitic precipitation hardening corrosion resistant steel;

TRIP steel;

21-6-9 austenitic corrosion resistant steel;

5Aℓ-2.5 Sn ELI titanium alloy;

6Aℓ-4V ELI titanium alloy.

During Tasks II, III, and IV the alloys were subjected to a series of treatments and tests that were designed to determine how the room temperature tensile properties of each alloy were affected when the alloy was strained at cryogenic temperatures.

Of the 15 alloys tested, only two, PH 4-8 Mo and MP 35 N, showed a significant response to cryostraining. Both of these alloys undergo strain-induced phase transformations, and each alloy is strengthened by the transformation. For PH 14-8 Mo it is an austenite-to-martensite transformation, while for MP 35 N, platelets of a hexagonal-close-packed phase form within the face-centered cubic (fcc) structured matrix. The transformation in each alloy is apparently enhanced when the alloy is strained at a cryogenic temperature.

Seven other alloys, 6061, 5456, Inconel 718, Nickel 440, beryllium copper, A-286, and 21-6-9, were found to have a higher uniform strain capability at one or more of the cryogenic temperatures than at room temperature. Consequently, these alloys can be strained greater amounts, and thus strengthened more, when they are strained at cryogenic temperatures than when they are strained at room temperature. The magnitude of the strength increase that can be achieved by straining these alloys at cryogenic temperatures is so small (proportionally), however, that cryostraining does not appear to merit consideration as a practical method for strengthening them.

Straining at room remperature is equally as effective a method for strengthening 2219, L-605, LA141A, TRIP steel, 6Aℓ-4V ELI, and 5Aℓ-2.5 Sn ELI, as is straining them at cryogenic temperatures.

I. INTRODUCTION

Background

Deforming a metal plastically at a temperature lower than its recrystallization temperature, is the accepted definition for cold working of metals. Generally, a metal is strengthened and hardened by cold work, while its toughness and ductility are reduced. The magnitude of the strengthening, hardening, and other effects wrought by cold working vary greatly from alloy to alloy and are dependent upon alloy base, chemical composition and other factors. While the effects of cold working have long been recognized and used effectively as a means of strengthening metals, the mechanism of strain hardening has not yet been completely explained. A number of theories have been presented, none of which satisfactorily explain all of the observed facts. The dislocation theory of strain hardening is currently the most generally accepted strain hardening theory.

Although the exact mechanism by which metals strain harden is unknown, metals are cold worked by numerous processes and methods. Generally, these processes involve the straining, or working, of the metal at a temperature somewhere between the metal's recrystallization temperature and room temperature. However, the working of metals at temperatures appreciably below room temperature has not been fully investigated or exploited. Some phenomenological studies have been conducted, for example; Wellinger and Seufert (ref. 1) have reached a conclusion that metals and alloys with a face-centered cubic (fcc) structure when partially worked at low temperatures retain some of their increased resistance to deformation when they are further strained at room temperature. Body-centered cubic (bcc) structured metals and alloys do not exhibit this characteristic. The authors show that this behavior is in accord with the dislocation theory of strain hardening. Ripling (ref. 2) discusses in detail the ductility deficiency observed when metals and alloys with other than a fcc structure are strained at low temperatures. Liu and Ripling (ref. 3) report that prestraining 2024-T4 aluminum alloy (fcc structure) at low temperatures produced higher room temperature flow curves than did equal prestrains at room temperature. An interesting feature to note in reviewing the behavior of metals at cryogenic temperatures, particularly those with a fcc structure, is that the temperature dependence of the ultimate tensile strength is greater than that of the yield strength. Therefore, these materials can be plastically deformed greater amounts, without necking, at temperatures below room temperature than they can at room temperature. The increased capability for plastic deformation at low temperatures, together with the tendency for a metastable 17-7 (301) or on 18-8 ELC (304L) stainless steel to undergo a strain-induced austenite-to-martensite transformation when strained at low temperatures, are the bases for the Ardeform Process,* developed by Arde, Inc., Paramus, N. J.

Some alloys can be more efficiently and effectively strengthened by thermal treatment than by cold work. Other alloys respond to combined treatments, and others, like pure metals, cannot be strengthened by thermal treatment.

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* Patent No. 3,197,851; 3 August 1965.

The two types of thermal treatment used to strengthen metal alloys that are pertinent to the program are: (1) those used to effect a polymorphic transformation; and (2) those classified as precipitation hardening treatments. The classic example of the first type of treatment is the austenitize-quench-temper treatment by which many steels are strengthened. The precipitation treatment is exemplified by the process used to strengthen the heat-treatable aluminum alloys. This process involves heating the material to a temperature somewhat lower than the melting temperature of the alloy to form a solid solution. From this temperature the material is rapidly cooled (quenched) to produce a supersaturated solid solution at room temperature. The material is then reheated to a temperature lower than the solution treatment temperature to promote the precipitation of submicroscopic particles of a second phase within the matrix. The first operation of this sequence is the solution treatment, the latter, the precipitation or artificial aging treatment.

The aging kinetics of some precipitation hardening alloys can be altered if the material is plastically deformed after it has been solution treated and quenched and before it is artificially aged. Two examples of this effect are shown in the following tabulation.

Alloy	Cold work, % (after solution treatment and before aging)	Ultimate tensile strength		Tensile yield strength, 0.2% offset	
		ksi	N/cm^2	ksi	N/cm^2
2219-T6	0	61	42×10^3	45	31×10^3
2219-T81	1-3	66	46×10^3	48	33×10^3
2219-T87	7-10	69	47×10^3	58	40×10^3
Inconel 718	0	195	134×10^3	170	117×10^3
Inconel 718	30	225	115×10^3	210	145×10^3
Inconel 718	50	245	170×10^3	225	155×10^3

This report is an account of the results obtained during the first year of a two-year test program being conducted under Contract NAS3-12028. The objective of the program is to find a metallic alloy that can be significantly strengthened by cryostraining, and yet will retain sufficient toughness, corrosion resistance, and other essential characteristics, so that its usefulness as a structural material is not lost.

Approach

The program is divided into two parts, each of one-year duration. During the first year, 15 alloys were selected for investigation and subjected to screening tests to determine the alloys for which cryostraining is a potentially practical strengthening process. The same basic plan was followed in testing each alloy, specifically:

1) Specimens were strained at four temperatures: room temperature; -110°F (194°K); -320°F (78°K); and -423°F (20°K);

2) Three groups of specimens were strained at each temperature, one group to each of three predetermined target strains. The target strains were selected to allow all specimens to be strained plastically but uniformly, with no necking or fracture;

3) Another group of specimens was soaked but not strained at each temperature;

4) For heat treatable alloys, one-half of each group of specimens that had been soaked or strained at a temperature were given an appropriate aging treatment;

5) Room temperature tensile tests were conducted on the specimens conditioned as indicated in 2), 3), and 4) above. The properties obtained were: ultimate tensile strength, tensile yield strength - 0.2% offset, and percent elongation.

Data from the first year's tests will serve as the basis for selecting a minimum of three alloys to be tested during the first task of the second year's program. From the results of these tests one alloy will be selected and subsequently tested to determine how cryostraining affects its response to thermal treatment (aging), fracture toughness, and stress corrosion resistance.

The Task outline of the two-year program is:

Task I - Materials Selection;

Task II - Preparation of Baseline and Cryosoaked Specimens;

Task III. - Preparation of Cryoworked Specimens;

Task IV - Room Temperature Testing;

Task V - Evaluation of Results;

Task VI - Selection of Promising Alloy;

Task VII - Thermal Response Tests;

Task VIII - Fracture Toughness, Stress Corrosion and High Energy Rate Tests;

Task IX - Analysis

Tasks I thru V collectively constitute the general screening program that was conducted during the first year. Tasks VI through IX are the second year's program. Following are summaries of each task.

Task I - Material Selection

The objective of the program places strong emphasis on investigating proven structural materials, particularly those with a high potential for use in aerospace applications. The most likely application for a cryostrain-hardened material is in pressure vessels, because the material can be formed and welded into the shape of a vessel and then, through the application of internal pressure, cryostrained as required. Consequently, when the materials were selected for the first year's program, priority was given structural materials, particularly those suitable for high strength tanks and aerospace structures. Other factors considered were:

1) Contract requirements - to select and test a minimum of 15 alloys, with no more than five alloys from any one base metal system;
2) A material's properties and characteristics, specifically;
   a) Crystal structure,
   b) Strain hardening characteristics,
   c) Thermal hardening characteristics,
   d) Phase transformations,
   e) Properties at cryogenic temperatures, particularly ductility,
   f) Weldability,
   g) Formability,
   h) Availability in sheet or strip form,

After a review of available data, the following alloys were selected, and subsequently, tested.

Aluminum alloys - 2119, 5456, and 6061;

Cobalt alloy - L-605;

Cobalt-nickel alloy - MP 35N;

Copper alloy - Beryllium copper;

Magnesium alloy - LA 141A;

Nickel alloys - Inconel 718, Nickel 440;

Steels - A-286, PH 14-8 Mo, TRIP, 21-6-9;

Titanium alloys - 6Aℓ-4V ELI, 5Aℓ-2.5Sn ELI.

Task II - Preparation of Baseline and Cryosoaked Specimens

A logical application for a cryostraining process is the fabrication of pressure vessels. One possible sequence of operations to produce a cryostrained vessel would be to form the component parts, weld them into the shape of a vessel, and cryostrain by applying an internal pressure to the vessel while it is immersed in a cryogen. Sufficient pressure could be applied to produce the desired amount of plastic strain. Processed in this manner a material would strain in tension. Consequently, for the first year's screening program the method of straining selected and used was uniaxial tension. The materials tested in the program were procured in the form of sheet or strip, therefore, the specimens used throughout Tasks II, III, and IV were standard flat tensile specimens, meeting the requirements of Federal Test Method Standard No. 151. The tests conducted under Tasks II, III, and IV were for the purpose of determining how the longitudinal tensile properties of each of the 15 alloys were affected when the alloy was strained at cryogenic temperatures.

Tests were conducted during Task II to determine how long a specimen had to be immersed in a cryogen before thermal equilibrium between the specimen and the bath was achieved. It was found that for the thin specimens being tested, thermal equilibrium between the specimen and bath was always achieved in less than two minutes. Anticipating that in some instances adjustments to the load linkage and other equipment could delay the start of the straining operation beyond the two minutes necessary to achieve thermal equilibrium, a standard prestrain soak time of five minutes was established for all specimens strained at -110°F (194°K), and -320°F (78°K). Because a closed system that required slow filling of the cryostat for each straining operation was used to strain at -423°F (20°K), a standard 30-minute prestrain soak time was established for that operation. To determine whether or not the 5- or 30-minute exposure to temperature before straining affected poststrain properties, during Task II, specimens of each alloy were exposed at the various cryogenic temperatures for the appropriated time period and subsequently tested in Task IV. A particular specimen was exposed to only one temperature. Generally, ten specimens of a heat treatable alloy were exposed at each temperature, while for nonheat treatable alloys, five specimens were exposed at each temperature. These specimens, referred to as cryosoaked specimens, are designated as 0% strained specimens in the figures in Chapter IV and in the tables of the Appendix.

During Task II the baseline specimens were also prepared, in the same quantity per alloy as the cryosoaked specimens. The baseline specimens are those designated in the tables and figures as 0% strained at room temperature.

Task III - Preparation of Cryostrained Specimens

Specimens of each alloy were prepared and strained according to the basic straining schedule, shown in the following tabulation. These specimens were tested in Task IV. Specific deviations from the basic schedule are noted and explained in Chapter IV, Test Results.

Straining temperature	Quantity of specimens strained					
	Strain level A[a]		Strain level B[a]		Strain level C[a]	
	Heat treatable alloy	Nonheat treatable alloy	Heat treatable alloy	Nonheat treatable alloy	Heat treatable alloy	Nonheat treatable alloy
Room Temp	10	5	10	5	10	5
-110°F (194°K)	10	5	10	5	10	5
-320°F (78°K)	10	5	10	5	10	5
-423°F (20°K)	10	5	10	5	10	5

[a]The term "strain level" was applied to the target strains that were developed for each alloy at each temperature. They were alloy and temperature dependent, and were computed as follows: Level A was the same value at all temperatures, it was set equal to 40% of the alloy's uniform strain capability at the temperature at which the alloy had the least uniform strain capability. Levels B and C, at a particular temperature, were set equal to 60% and 80%, respectively, of the alloy's uniform strain capability at that temperature.

The specimens were strained, uniaxial tension, using standard tensile machines, accessories, cryostats, and appropriate cryogens. A strain rate of 0.050 in./in./minute (0.050 cm/cm/min) was used to strain all specimens except the Ti 6Aℓ-4V ELI specimens. For these, a strain rate of 0.005 in./in./minute (0.005 cm/cm/min) was used.

Task IV - Room Temperature Tensile Tests

During Task IV the cryosoaked and cryostrained specimens prepared in Tasks II and III were subjected to standard room temperature tensile tests, conducted in accordance with the requirements of Federal Test Method Standard No. 151. For heat treatable alloys, one-half of each set of soaked or strained specimens were given an appropriate aging treatment before they were tested. The other half of each set were tested in the as-strained or as-soaked conditions, as were the specimens of the nonheat treatable alloys.

The aging treatments selected for the heat treatable alloys were industry standard treatments. Strain hardening accelerates the response of many of the alloys to aging treatments; consequently, when necessary, the aging treatment given unstrained specimens was different than that given strained specimens. Also, in some cases, two aging treatments were used for strained specimens, one appropriate for highly strained specimens, the other most suitable for lesser strained specimens. One of the treatments was selected as the primary treatment and the majority of the strained specimens were given that treatment. However, for comparison, at least one specimen of each set of strained specimens was given the alternative treatment.

Task V - Evaluation

The final task of the first year's program was the analysis of the data developed in conducting Tasks I thru IV. This report is an account of the first year's testing.

Task VI - Selection of Promising Alloy

The first task of the second year's program will consist of a number of subtasks, namely:

1) Selection of alloys to be tested. The results of Task IV testing will be the primary basis for selecting no less than three alloys to be evaluated in Task VI;

2) Tests will be conducted to determine the effect of straining at a cryogenic temperature on the room temperature longitudinal and transverse tensile properties of each alloy;

3) Tests will be conducted to determine how welding before straining affects postcryostrained tensile properties;

4) Tests will be conducted to determine how roll straining at a cryogenic temperature affects tensile properties;

5) Tests will be conducted to assess the effects of strain rate on post-cryostrained tensile properties.

Task VII - Thermal Response Tests

The results of the Task VI tests will be analyzed and the alloy that shows the best response to the tests will be selected for additional testing in Tasks VII and VIII.

Tests will be conducted to develop data needed to construct constant temperature aging response curves for the alloy in various cryostrained conditions.

Task VIII - Fracture Toughness, Stress Corrosion, and High Energy Rate Forming Tests

The effects of cryostraining on the fracture toughness and stress corrosion resistance of the alloy will be studied. Also, the effects of cryostraining by means of a high-energy rate forming method on the room temperature tensile properties of the alloy will be studied.

The following chapters of this report are an account of the first year of the program, Task I thru Task V.

II. MATERIALS SELECTION

The selection of materials to be tested during Tasks II, III, and IV was based on the overall objective of the program that places emphasis on structural alloys, particularly those suitable for high-strength pressure vessels. However, because 15 alloys were to be tested, it was possible to include several alloys on the basis of academic interest rather than because of their structural potential. The criteria for selecting the materials were:

1) Crystal structure (fcc, bcc, etc);
2) Strain hardening characteristics;
3) Thermal hardening characteristics;
4) Phase transformations;
5) Properties at cryogenic temperatures, particularly, ductility;
6) Weldability;
7) Formability;
8) Availability in sheet or strip form;
9) Potential for structural applications.

A literature search was initiated for sources of information on candidate alloys, specifically their behavior at cryogenic temperatures and how they are affected by straining at cryogenic temperatures. Actually, three separate machine searches were conducted, one through the National Aeronautics and Space Administration, one through the Department of Defense, and the third through the National Bureau of Standards. As a result of these searches, over 1100 reference documents were identified. The most significant results obtained from these references were:

1) The cryogenic properties of various metallic materials, particularly ultimate tensile, tensile yield, and elongation at temperatures to -423°F (20°K);
2) The relationship of various thermal treatments to cryogenic properties;
3) The crystalline structure of metallic materials and their relationship to cryogenic properties.

Unfortunately, most of the references did not provide information that was useful in selecting materials for this program. The only significant information regarding the cryogenic straining of metals was found in the data published by Arde, Inc.

Contacts were made with various personnel in industry who are producers, users, or investigators of metallic materials. These contacts proved to be extremely helpful, particularly in choosing between similar alloys for such reasons as presumed response to cryostraining based on composition, microstructure, and mechanical properties.

The following materials were selected for testing in Tasks II, III, and IV:

- 2219 aluminum alloy;
- 5456 aluminum alloy;
- 6061 aluminum alloy;
- Beryllium copper;
- L-605 cobalt alloy;
- MP 35 N cobalt-nickel alloy;
- LA141A magnesium alloy;
- Inconel 718 nickel alloy;
- Nickel 440 nickel alloy;
- A-286 austenitic precipitation hardening stainless steel;
- PH 14-8 Mo semiaustenitic precipitation hardening stainless steel;
- TRIP steel;
- 200 grade 18% nickel maraging steel;
- 21-6-9 austenitic stainless steel;
- 5Aℓ-2.5Sn ELI titanium alloy;
- 6Aℓ-4V ELI titanium alloy.

A brief discussion of each material follows.

Aluminum Alloy 2219

The density of aluminum alloy 2219 is 0.103 lb/cu in. (2.85 gm/cc). Its typical mechanical properties are shown in the following tabulation.

Condition	Ultimate tensile strength		Tensile yield strength, 0.2% offset		Elongation % in 2 in. (5.08 cm)
	psi	N/cm^2	psi	N/cm^2	
2219-0	25 000	17 000	11 000	7 500	18
2219-T31	52 000	36 000	36 000	25 000	17
2219-T81	66 000	46 000	51 000	35 000	10
2219-T87	69 000	48 000	57 000	39 000	10
2219-T62	60 000	41 000	42 000	29 000	10

The crystal structure of 2219 alloys is fcc.

The 2219 alloy is a moderately high-strength aluminum alloy that can be strengthened by thermal treatment and can be additionally strengthened if it is cold worked after the solution treatment and before the aging treatment. It has excellent welding characteristics and is available in most of the common wrought forms. It was chosen for the program over other 2xxx series aluminum alloys such as, 2014 and 2024, mainly because of its combination of strain hardening characteristics and weldability.

Aluminum Alloy 5456

The density of aluminum alloy 5456 is 0.096 lb/cu in. (2.66 gm/cc). Its typical mechanical properties are shown in the following tabulation.

Condition	Ultimate tensile strength		Tensile yield strength, 0.2% offset		Elongation % in 2 in. (5.08 cm)
	psi	N/cm^2	psi	N/cm^2	
5456-0	45 000	31 000	23 000	16 000	24
5456-H311	51 000	35 000	37 000	26 000	16

The crystal structure of 5456 alloy is fcc.

The 5456 alloy is one of the higher strength alloys of the 5xxx series of work hardening alloys; it is not strengthened by thermal treatment. Magnesium is the major alloying element of 5456. This alloy welds readily, has excellent corrosion resistance, and is available in most wrought forms. It was included in the program because of its strain hardening capability.

Aluminum Alloy 6061

The density of aluminum alloy 6061 is 0.098 lb/cu in. (2.71 gm/cc). Its typical mechanical properties are shown in the following tabulation.

Condition	Ultimate tensile strength		Tensile yield strength, 0.2% offset		Elongation % in 2 in. (5.08 cm)
	psi	N/cm^2	psi	N/cm^2	
6061-0	18 000	12 000	8 000	5 500	25
6061-T4	35 000	24 000	21 000	14 000	22
6061-T6	45 000	31 000	40 000	28 000	12

The crystal structure of 6061 alloys is fcc.

The 6061 alloy is a moderate strength, heat treatable, aluminum alloy, weldable and with excellent corrosion and stress corrosion resistance. The major alloying elements of 6061 are magnesium and silicon. This alloy is available in all wrought forms. It is used extensively in structural applications and is a popular material for cryogenic applications.

Beryllium Copper

The density of beryllium copper is 0.297 lb/cu in. (8.23 gm/cc). Its typical mechanical properties are shown in the following tabulation.

Condition	Ultimate tensile strength		Tensile yield strength, 0.2% offset		Elongation % in 2 in. (5.08 cm)
	psi	N/cm^2	psi	N/cm^2	
Annealed	60 000	41 000	---	---	35
½ H (half hard)	85 000	59 000	---	---	5
AT (hardened)	175 000	121 000	130 000	90 000	5
½ HT (hardened)	195 000	134 000	140 000	97 000	3

The crystal structure of beryllium copper is fcc.

Beryllium copper (Copper Development Association No. 172) is a copper base wrought alloy that is strengthened by both cold work and thermal treatment. It has excellent cryogenic properties, forms readily in the annealed condition, and is weldable. It is one of the highest strength copper alloys.

MP 35 N Cobalt Nickel Alloy

The density of MP 35 N is 0.304 lb/cu in. (8.41 gm/cc). Its typical mechanical properties are shown in the following tabulation.

Condition	Ultimate tensile strength		Tensile yield strength, 0.2% offset		Elongation % in 2 in. (5.08 cm)
	psi	N/cm^2	psi	N/cm^2	
Annealed	132 000	91 000	53 000	37 000	68
Work strengthened and aged	300 000	207 000	290 000	200 000	9

The crystal structure of MP 35 N (annealed) is fcc.

MP 35 N is a cobalt-nickel multiphase alloy combining high strength with good ductility, toughness, and excellent corrosion resistance. It is a strain hardening alloy that is further strengthened by a poststrain aging treatment. Strengths in the range of 260 000 psi (179 000 N/cm^2) can be achieved through combination strain hardening-aging treatments. MP 35 N has a face centered cubic matrix of cobalt and nickel in which the alloying elements chromium and molybdenum are soluble at elevated temperatures. The face centered cubic structure is retained when cooled to room temperature. A local shear transformation is induced, however, when MP 35 N is worked at temperatures below approximately 850°F (728°K), the equilibrium transformation temperature; small platelets of a hexagonal close packed structure form (locally) within the face centered cubic matrix. Unlike the martensite transformation in steel, this transformation does not appear to have an M_s temperature at which it occurs on cooling. The amount of the hexagonal close packed phase formed is dependent upon the amount of strain deformation. The transformed product is stable.

L-605

The density of L-605 is 0.330 lb/cu in. (9.13 gm/cc). Its typical mechanical properties are shown in the following tabulation.

Condition	Ultimate tensile strength		Tensile yield strength, 0.2% offset		Elongation % in 2 in. (5.08 cm)
	psi	N/cm^2	psi	N/cm^2	
Annealed	130 000	90 000	55 000	38 000	45

The crystal structure of L-605 is hcp.

L-605 is a cobalt base alloy that is strengthened by cold work and subsequent aging. It is used extensively in temperatures up to 2000°F (1367°K) and has reasonable strength and ductility at cryogenic temperatures. The alloy is available in most wrought forms, has good corrosion resistance, and is readily weldable.

LA141A Magnesium Alloy

The density of LA141A is 0.048 lb/cu in. (1.36 gm/cc). Its typical mechanical properties are shown in the following tabulation.

Condition	Ultimate tensile strength		Tensile yield strength, 0.2% offset		Elongation % in 2 in. (5.08 cm)
	psi	N/cm^2	psi	N/cm^2	
LA141A-T7	19 000	13 000	15 000	10 000	10

The crystal structure of LA141A is bcc.

LA141A is a magnesium lithium alloy with a very low density, and relatively good ductility and workability. It is weldable, age hardenable, and has about the same corrosion resistance as conventional magnesium alloys.

Inconel 718

The density of Inconel 718 is 0.297 lb/cu in. (8.21 gm/cc). Its typical mechanical properties are shown in the following tabulation.

Condition	Ultimate tensile strength		Tensile yield strength, 0.2% offset		Elongation % in 2 in. (5.08 cm)
	psi	N/cm^2	psi	N/cm^2	
Annealed	150 000	103 000	90 000	62 000	40
Aged	190 000	131 000	160 000	110 000	20

The crystal structure of Inconel 718 is fcc.

Inconel 718, a wrought, age hardenable nickel-chromium alloy was origninally developed for elevated temperature applications. However, it has proved suitable for cryogenic applications as well. It is work hardenable as well as age hardenable, forms readily, is weldable, and has excellent corrosion resistance. It is available in common wrought forms.

Nickel 440

The density of Nickel 440 is 0.302 lb/cu in. (8.86 gm/cc). Its typical mechanical properties are shown in the following tabulation.

Composition	Ultimate tensile strength		Tensile yield strength, 0.2% offset		Elongation % in 2 in. (5.08 cm)
	psi	N/cm^2	psi	N/cm^2	
Annealed	95 000	66 000	45 000	28 000	30
½ H (half hard)	130 000	90 000	65 000	45 000	4
AT (hardened)	215 000	148 000	150 000	103 000	12
½ HT (hardened)	245 000	169 000	200 000	138 000	9

The crystal structure of Nickel 440 is fcc.

Nickel 440 is a nickel-base alloy that has cryogenic properties to -423°F (20°K) competitive with other materials currently used for cryogenic applications. It is an age-hardenable alloy that attains peak mechanical properties by precipitation hardening from either the solution heat treated condition or from various cold worked tempers. The hardening mechanism is a dispersion of fine beryllide particles. This alloy has good elevated temperature properties up to 800°F (700°K), good formability, and excellent corrosion resistance in a reducing media. It is weldable by the tungsten inert gas (TIG) process.

A-286 Corrosion Resistant Steel

The density of A-286 is 0.286 lb/cu in. (7.92 gm/cc). Its typical mechanical properties are shown in the following tabulation.

Condtion	Ultimate tensile strength		Tensile yield strength, 0.2% offset		Elongation, % in 2 in. (5.08 cm)
	psi	N/cm^2	psi	N/cm^2	
Annealed	105 000	72 000	---	---	25
Aged	140 000	97 000	95 000	66 000	15

The crystal structure of A-286 is fcc.

A-286 is an austenitic precipitation hardening corrosion-resistant steel. Additional strengthening can be achieved by cold working. Although originally developed for elevated temperature applications it has been found to be equally suited for cryogenic temperature applications. It is a higher strength material than the 300 series stainless steels. At cryogenic temperatures, because of its austenitic structure, it has good ductility and toughness. A-286 has excellent corrosion resistance, is weldable, and compares favorably with the 300 stainless steels in respect to forming.

PH 14-8 Mo Corrosion Resistant Steel

The density of PH 14-8 Mo is 0.283 lb/cu in. (7.82 gm/cc). Its typical mechanical properties are shown in the following tabulation.

Condition (vaccum induction melted)	Ultimate tensile strength		Tensile yield strength, 0.2% offset		Elongation, % in 2 in. (5.08 cm)
	psi	N/cm^2	psi	N/cm^2	
A	125 000	86 000	55 000	38 000	25
SRH 950	230 000	156 000	215 000	148 000	6
CH 900	280 000	193 000	270 000	186 000	1.5

The crystal structure of PH 14-8 Mo, Condition A, is fcc.

PH 14-8 Mo is a semi-austenitic precipitation hardening corrosion - resistant steel. Vacuum melted material, the type used in this program, is tougher than air melted material. In the solution-treated condition (Condition A) the structure of this alloy is essentially austenitic. Transformation to martensite can be accomplished either by thermal treatment or by cold working. Aging after transformation results in additional strengthening. The alloy is very formable in the annealed (solution treated) condition and is weldable.

TRIP Steel

TRIP steels represent a new class of steels that show increased ductility at high strengths compared with other ferrous base materials. The processing of these steels is a fairly complex thermomechanical treatment, and the final properties are based on mutual interactions of solid solution strengthening, precipitation strengthening, work hardening, and transformation (austenite to martensite) strengthening. After the thermomechanical treatement, the structure is austenitic. The application of an applied stress induces transformation to martensite. The literature states that the good ductility shown by these steels results from the transformation occurring during straining. This concept led to the name TRIP, an acronym for TRansformation Induced Plasticity. This material is not currently used in production, but was considered to have sufficient unique characteristics to warrant investigation in this program.

21-6-9 Corrosion Resistant Steel

The density of 21-6-9 is 0.283 lb/cu in. (7.82 gm/cc). Its typical mechanical properties are shown in the following tabulation.

Condition	Ultimate tensile strength		Tensile yield strength, 0.2% offset		Elongation, % in 2 in. (5.08 cm)
	psi	N/cm^2	psi	N/cm^2	
Annealed	100 000	69 000	55 000	38 000	40
Cold rolled 50%	192 000	132 000	175 000	121 000	7

The crystal structure of annealed 21-6-9 is, fcc.

The 21-6-9 material is an austenitic corrosion resistant steel. It has a higher annealed yield strength than the 300 series stainless steels, and like them, it is strengthened by cold working, but not by thermal treatment. Also, 21-6-9 is comparable to the 300 series stainless steels in weldability, formability, and corrosion resistance. It is available in many common wrought forms.

5Aℓ-2.5Sn ELI Titanium Alloy

The density of 5Aℓ-2.5Sn is 0.162 lb/cu in. (4.48 gm/cc). Its typical mechanical properties are shown in the following tabulation.

Condition	Ultimate tensile strength		Tensile yield strength, 0.2% offset		Elongation, % in 2 in. (5.08 cm)
	psi	N/cm^2	psi	N/cm^2	
Annealed	120 000	83 000	115 000	79 000	10

The crystal structure of 5Aℓ-2.5Sn is hcp.

The 5Aℓ-2.5Sn ELI titanium alloy is an alpha alloy with extra low interstitial (ELI) content, which improves its toughness at cryogenic temperatures. This alloy is nonheat treatable, but has much higher properties than unalloyed titanium. It is one of the most widely used structural materials in the temperature range of -320°F (78°K) to -423°F (20°K) because at those temperatures it combines good ductility and fracture toughness with a high strength-to-weight ratio. The material has good corrosion resistance, welds easily, and is available in most wrought forms.

6Aℓ-4V ELI Titanium Alloy

The density of 6Aℓ-4V is 0.160 lb/cu in. (4.43 gm/cc). Its typical mechanical properties are shown in the following tabulation.

Condition	Ultimate tensile strength		Tensile yield strength, 0.2% offset		Elongation, % in 2 in. (5.08 cm)
	psi	N/cm^2	psi	N/cm^2	
Annealed	130 000	90 000	120 000	83 000	10
STA	160 000	110 000	145 000	100 000	6

The crystal structure of 6Aℓ-4V is hcp + bcc.

The 6Aℓ-4V ELI titanium alloy is an alpha-beta alloy that is heat treatable. The ELI grade shows increased ductility and toughness at cryogenic temperatures compared with the normal interstitial grade. This material is currently one of the most widely used structural materials in the aerospace industry, particularly for pressure vessels, because of its high strength-to-weight ratio. It is readily available in most wrought forms, is formable, and can be welded readily.

III. TEST PROCEDURES AND APPARATUS

During the period covered by this Interim Report, the first year of a two-year program, 15 metallic alloys were tested. The tests were conducted to determine how the room temperature longitudinal tensile properties of each alloy were affected when the alloy was strained (uniaxial tension) at cryogenic temperatures. The procedures used to accomplish this objective are described in following paragraphs. Each basic operation is treated separately. The operations are presented in the sequence in which they were conducted.

Material Procurement and Inspection

All material was procured to an applicable specification -- Federal, Military, or commercial -- as appropriate. The materials were procured in either sheet or strip form and the entire lot of any material was from the same heat.

Receiving inspection tests were conducted on all the materials. These included visual examination, dimensional inspection, chemical analysis, confirmation of mechanical properties, and when appropriate, examination of the microstructure.

Specific information regarding the form, condition, size, and composition, in which each material was procured are given in Chapter IV, "Test Results and Discussion."

Preparation of Specimens

<u>Gridding</u> - To accomplish the objectives of the program it was necessary to strain each material at four temperatures: room temperature, -110°F (194°K), -320°F (78°K), and -423°F (20°K). Because tensile straining has direct application to the production of pressure vessels, that method of straining was used in the program. Consequently, straining and testing were done on standard tensile machines, and the specimens strained or tested were standard, flat, friction loaded or pin loaded tensile bars. To facilitate strain measurement each specimen had a 0.100-in. (0.254 cm) square grid pattern applied to one surface (Fig. 1). This pattern was applied by a photographic process. For efficiency, the pattern was applied, not to individual specimens, but to the largest piece of material that could be obtained from the stock and accommodated by the photographic process. The largest piece of material that could be gridded was, t (thickness) x 24 in. (60.96 cm.) wide x 24 in. (60.96 cm) long. To prepare specimens, the sheet or strip was first sheared into pieces of appropriate size for gridding. Each sheared piece was marked to identify alloy and grain direction, and was then gridded. The gridded stock was then sheared to specimen blank size; t x 7/8 in. (2.22 cm) wide x 8 in. (20.32 cm) long for friction loaded specimens; and, t x 1 5/8 in. (4.13 cm) wide x 8 in. (20.32 cm) long for pin-loaded specimens. In each case the 8 in. (20.32 cm) dimension was parallel to the longitudinal grain direction of the raw material.

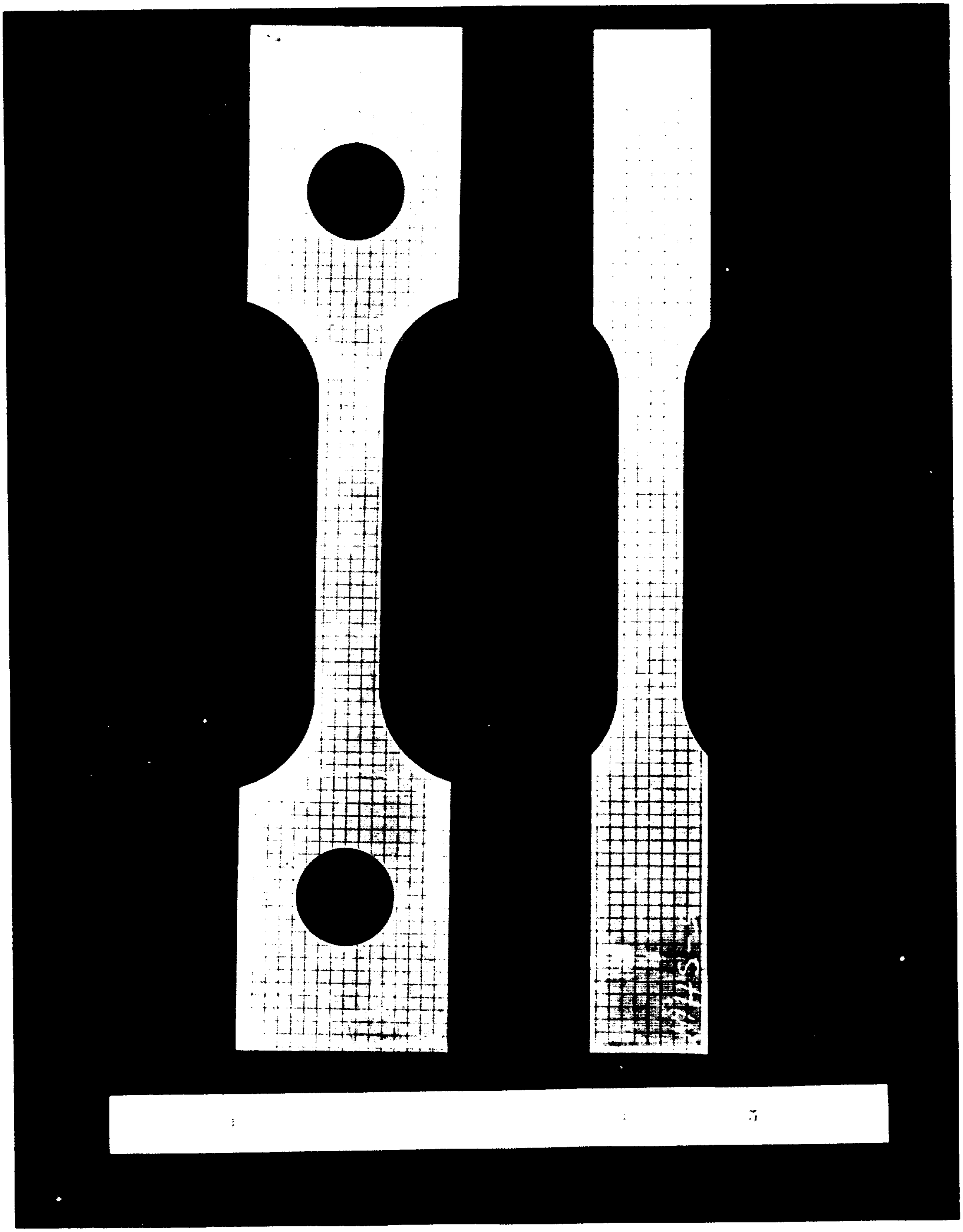


Figure 1.- Tensile Specimens with a 0.100-in.-square (0.254 cm) Photogrid Pattern on their Surfaces

Machining - The prepared blanks were machined in lots of 20 or more, depending on material thickness and the number of specimens to be made. The fixture and setup used to machine the blanks into specimens are shown in Figure 2. The use of this fixture allowed both sides of a pack of specimens to be machined without refixturing. This was done by using precision ground Vee blocks as supports and locators for the fixture. After one side of a pack of specimens was machined, the fixture was lifted off the Vee blocks, turned over, rotated 180°, and replaced on the Vee blocks. The other side of the pack was then machined.

The friction loaded specimen, shown in Figure 3 (a), was the type generally used for straining and testing at room temperature, -110°F (194°K), and -320°F (78°K). The pin loaded specimen Figure 3 (b), was used for testing and straining at -423°F (20°K).

Establishing uniform strain capabilities - A minimum of two specimens of each alloy were tested to failure in uniaxial tension at each of the four straining temperatures. Each alloy was tested in the same temper or condition in which specimens of the alloy were subsequently strained. The tests were conducted in accordance with the requirements and procedures of Federal Test Method Standard No. 151 (ASTM E8-66), except that cryostats and appropriate cryogens were used for testing at cryogenic temperatures. The purpose of these tests was to establish the total and the uniform elongation capabilities of each alloy at each temperature. Total elongation was measured across the fracture over a gage of 2-in. initial length (fig. 4). Uniform elongation was measured over a gage of 1-in. initial length (fig. 4). A 6-in. rule with 0.010-in. graduations and a 10X magnifying glass were used to measure the elongations. An alloy's uniform strain capability at a temperature was the term applied to the average of the uniform elongations measured on the specimens of the alloy that had been tested to failure at a temperature. A uniform strain capability value was established for each material for each straining temperature.

Selection of strain levels - Three amounts of strain, target values, designated as strain levels A, B, and C were established for each alloy for each straining temperature. These values were alloy dependent and for each alloy were computed as follows:

Level A - 40% of the material's uniform strain capability at that temperature where the material had the least uniform strain capability;

Level B - 60% of the material's uniform strain capability at the straining temperature;

Level C - 80% of the material's uniform strain capability at the straining temperature.

For any alloy then, Level A was the same for all temperatures, while Levels B and C varied with temperature. For clarification, the following tabulation shows, for an imaginary material, the material's uniform strain capability and attendant strain levels A, B, and C, at four straining temperatures.

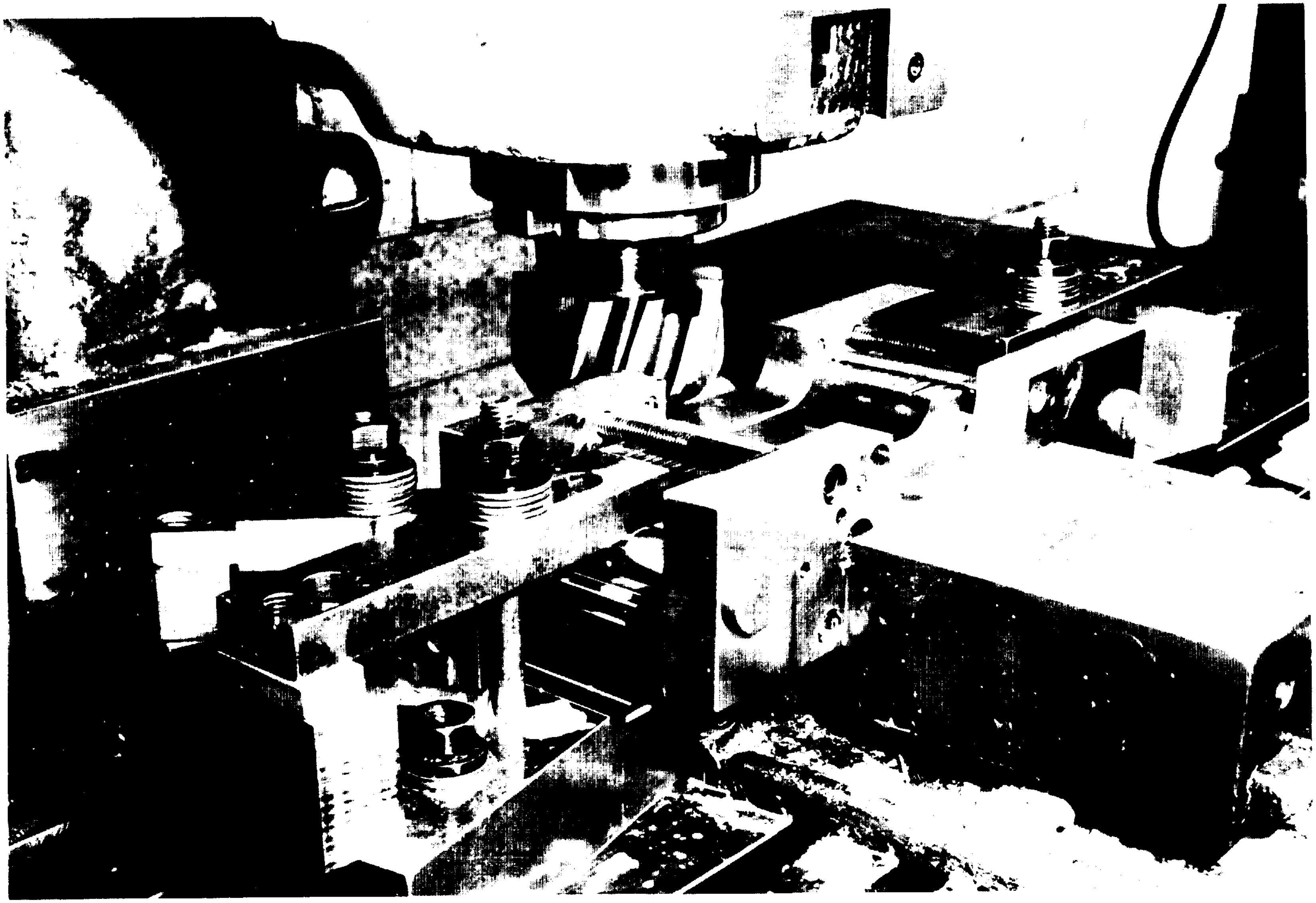
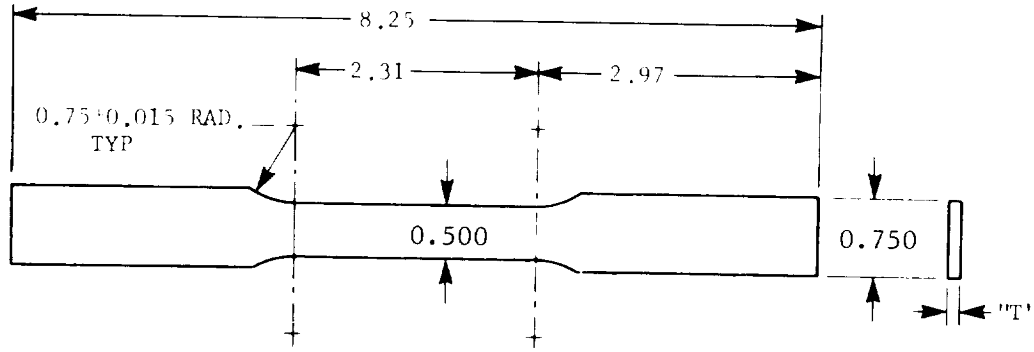
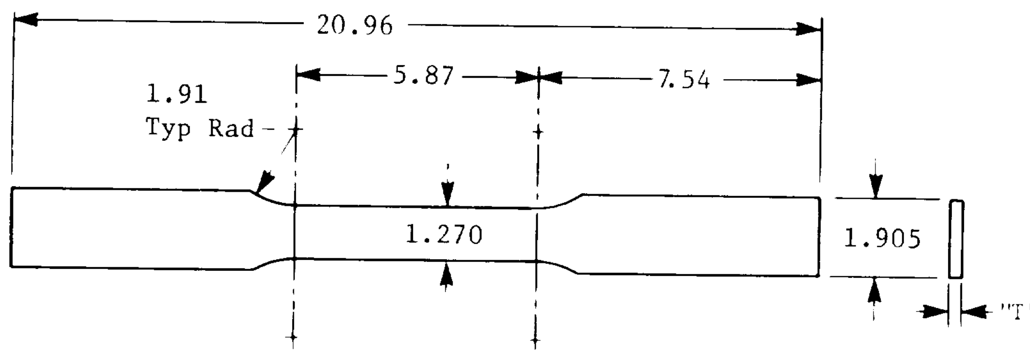


Figure 2.- Fixture and Setup for Machining Specimens



Note: All dimensions in inches.

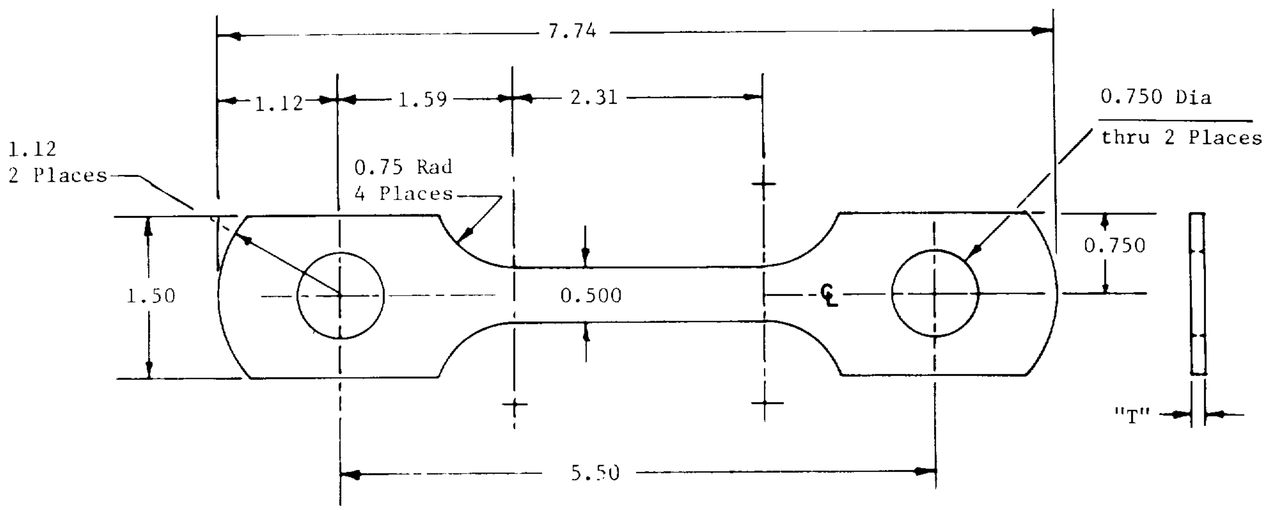


Note: All dimensions in centimeters.

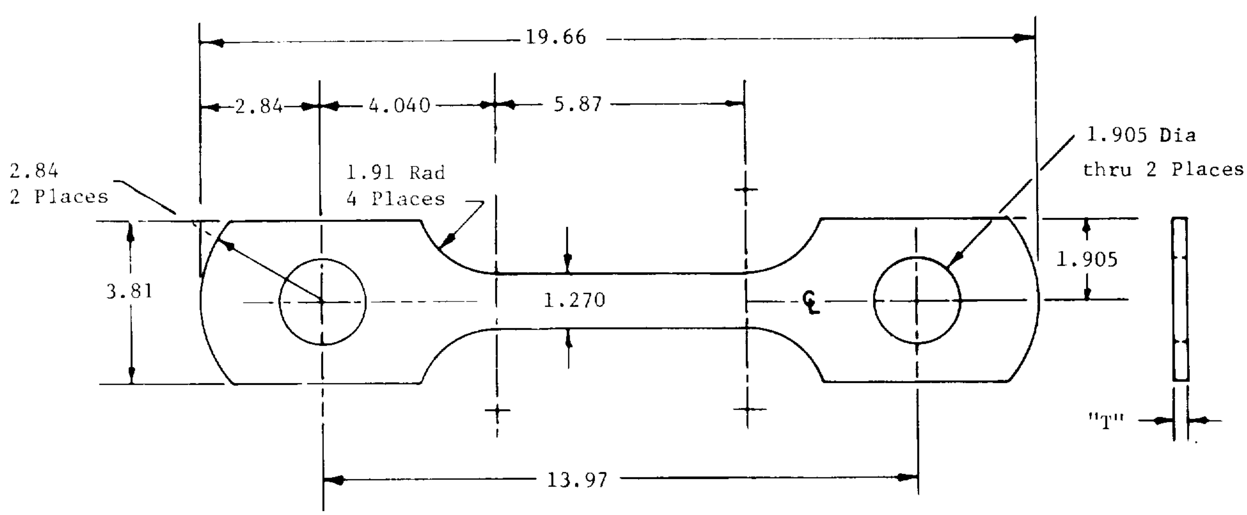
(a) Room Temperature, -110°F (194°K), and -320°F (78°K)

Figure 3 Specimen Configuration Used for Straining at Various Temperatures

Note: All dimensions in inches.



Note: All dimensions in centimeters.



(b) -423°F (20°K)

Figure 3-- Concluded

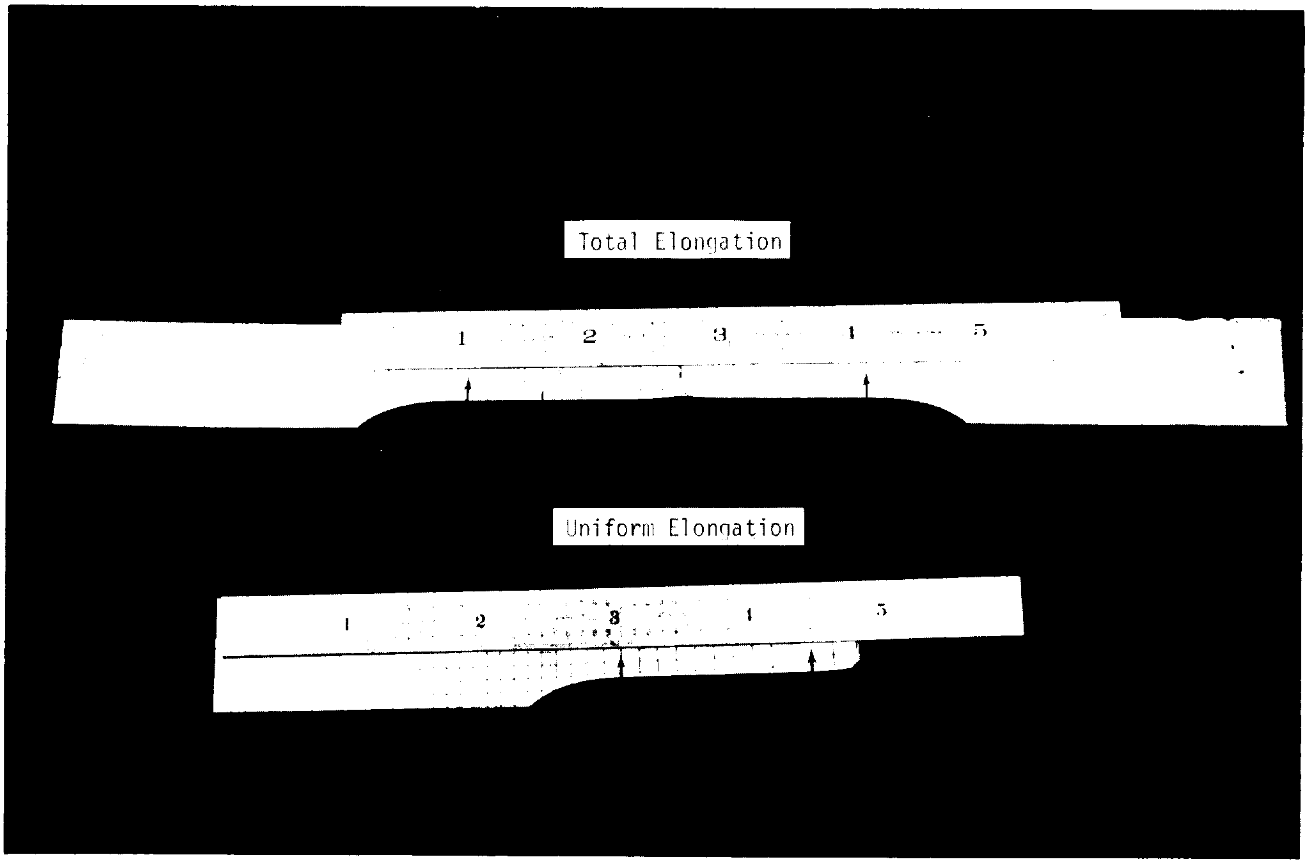


Figure 4.- Measurement of Total and Uniform Elongations

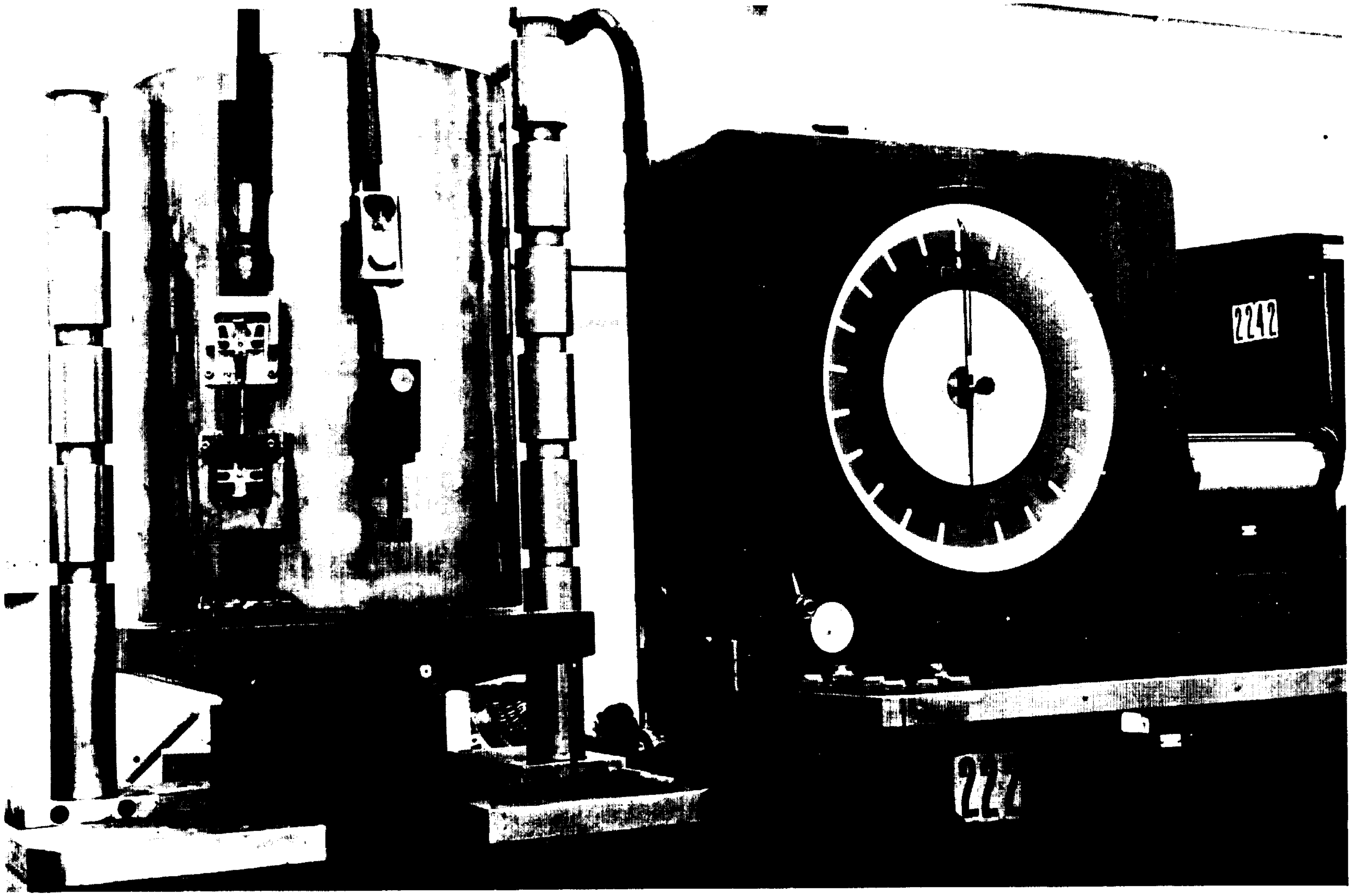


Figure 5.- Cryostat and Linkage Systems Used for Straining at -110°F (194°K) and -320°F (78°K).

Straining Temperature °F	Straining Temperature °K	Uniform Strain Capability, %	Strain level, % A	Strain level, % B	Strain level, % C
Room temp	Room temp	20.0	6.0	12.0	16.0
-110	194	25.0	6.0	15.0	20.0
-320	78	30.0	6.0	18.0	24.0
-423	20	15.0	6.0	9.0	12.0

Cryosoaking - Not all specimens were strained before they were tested. Some were merely exposed to one of the three cryogenic temperatures for a period of time and then tested, or heat treated and tested, as appropriate. In the text, figures, and the tables of the Appendix, the exposed and unstrained specimens are referred to as 0% strained. Soaking at cryogenic temperature, was accomplished by immersing the specimens in the appropriate cryogen for a predetermined period of time; 5 minutes minimum at -110°F (194°K) and -320°F (78°K); and 30 minutes minimum at -423°F (20°K). The cryogens were: -110°F (194°K), a mixture of isopropyl alcohol and dry ice; -320°F (78°K), liquid nitrogen (LN_2); and -423°F (20°K), liquid nitrogen (LH_2). Open top cryostats were used to soak specimens at -110°F (194°K), and at -320°F (78°K). A closed cryostat and remotely operated closed system (for safety purposes) were used for soaking specimens at -423°F (20°K).

Straining - For straining at room temperature, -110°F (194°K), and -320°F (78°K), friction loaded specimens were used and strained on one of two tensile machines, a 5000 lb. (22 200 N) capacity machine, or a 50 000 lb. (222 400 N) capacity machine. At -423°F (20°K) a 50 000 lb (222 400 N) machine and pin loaded specimens were used. All materials were strained at a rate of 0.050 in./in./min (0.050 cm/cm/min), except 6Aℓ-4V ELI titanium, which was strained at a rate of 0.005 in./in./min (0.005 cm/cm/min.).

When specimens were strained at room temperature, strain was measured directly by holding a 4-in. long scale (0.010-in. divisions) against the gridded surface of the specimen as it was being strained. Strain was measured over a gage of 2 in. (5.08 cm) initial length. Straining was stopped when a predetermined amount of strain was measured. Since elastic as well as plastic strain was measured while the specimen was under load, the strain measured under load always exceeded the target strain to compensate for the elastic shrinkage that occured when the load was released. After a specimen had been strained and removed from the tensile machine the actual amount of strain was measured and recorded. Strain was measured over a gage of 2 in. (5.08 cm) initial length, using the grid marks, a 6-in. scale (0.010-in. divisions) and a 10X magnifying glass.

Straining at -100°F (194°K) and at -320°F (78°K) was done on the same tensile machines that were used to strain specimens at room temperature. Open top cyostats and linkage systems (fig. 5) were also required. For -110°F (194°K) the cryogen was a mixture of dry ice and isopropyl alcohol, for -320°F (78°K) LN_2 was used. Whenever a setup was made for straining at either -110°F (194°K) or -320°F (78°K), the procedure included cooling the specimen grips to bath temperature by immersing them in the bath. When the grips had cooled, a specimen was loaded into them and the whole assembly was connected to the cryostat and tensile machine. The level of the cryogen in the cryostat was controlled so that the upper grip was always completely immersed. A specimen was never strained until it had been in the bath for at least 5 minutes. This 5-minute delay from immersion to straining was sufficient, as determined by experimentation, to assure that thermal equilibrium between specimen and bath had been achieved. A dial indicator was used to measure platen travel, which through experimentation, had been correlated to strain. After a specimen was strained at -110°F (194°K) or -320°F (78°K) it was warmed to room temperature and the actual strain was measured and recorded in the same way as it was on the room temperature strained specimens.

Straining at -423°F (20°K) was done in LH_2. To meet rigid safety requirements it was necessary to use equipment at the Liquid Hydrogen Laboratory. This equipment included a 50 000 (222 400 N) capacity tensile machine, and a remotely operated closed system, complete with cryostat, for filling, draining and purging the cryostat, and operating the tensile machine. Each strain cycle consisted of: loading specimens into the load linkage connected to the empty and purged cryostat; closing the system; filling the cryostat with LH_2; straining (platen travel was measured); draining and purging the cryostat; and removing the specimens. Because of the complexity of this cycle, pin loaded specimens were used. Their use permitted more than one specimen to be strained at a time. Usually five specimens were strained simultaneously, but the exact quantity was dependent on the strength of the material being strained and the 50 000 lb (222 400 N) capacity of the tensile machine. After being strained, specimens were warmed to room temperature and the actual strain was measured and recorded in the same way as it was for room temperature strained specimens.

Thermal treatments - All thermal treatments were performed in forced air circulation furnaces certified to military standards except for the solution heat treatment of 6Aℓ-4V titanium alloy that was performed in a vacuum furnace. Before any thermal treatment the specimens were:

1) Vapor degreased;
2) Water rinsed;
3) Alkaline cleaned;
4) Water rinsed;
5) Thoroughly dried (air or oven).

Specimens that required aging at temperatures above 900°F (756°K) were coated with a protective lacquer.

Testing

Mechanical Properties - One-half of each set of soaked or strained specimens of a heat treatable alloy were aged before they were tested. The other specimens of each set were tested in the as-soaked or as-strained condition, as were the specimens of nonheat treatable alloys.

Strained and soaked specimens were tested at room temperature on either a 5000 lb (22 200 N) capacity, or a 50 000 (222 400 N) capacity tensile machine, depending upon the strength of the material. The equipment and procedures used conformed with the requirements of Federal Test method Standard No. 151 (ASTM E8-66). A load-strain curve was autographically recorded for each test. For this purpose an extensometer with a 2-in. (5.08 cm) gage together with appropriate strain magnifying and plotting devices were used. The properties determined form each test were: ultimate tensile strength; tensile yield strength, 0.2% offset; and total elongation, percent in 2 in. (5.08 cm).

Metallurgical analyses - Metallurgical analyses were performed on selected specimens of each material to determine their microstructure in the as-received condition to the final processed condition. Microstructural characteristics were studied. This study was primarily performed using standard light microscopy techniques up to 750X.

Summary of Processing

In summary, the sequence of processing the materials investigated in this program is shown in table 1. When deviations were made from this sequence or in number of specimens processed at any particular step, it is discussed under Test Results for that particular material.

Table 1 Sequential Processing of Materials

Obtain raw material → Shear → Grid → Machine specimens per fig 3 (a) and fig 3 (b)

Determination of uniform strain at indicated temperature, °F,[b] (number of specimens)	Straining[a]: Temp, °F[b], and strain level	Straining[a]: Number of specimens[c]	Received poststrain thermal treatment, number of specimens[c]: Yes	Received poststrain thermal treatment, number of specimens[c]: No	Specimens tested at room temp[c]
RT (2)	RT, 0%	10	5	5	10
	RT, level A	10	5	5	10
	RT, level B	10	5	5	10
	RT, level C	10	5	5	10
-110 (2)	-110, 0%	10	5	5	10
	-110, level A	10	5	5	10
	-110, level B	10	5	5	10
	-110, level C	10	5	5	10
-320 (2)	-320, 0%	10	5	5	10
	-320, level A	10	5	5	10
	-320, level B	10	5	5	10
	-320, level C	10	5	5	10
-423 (2)	-423, 0%	10	5	5	10
	-423, level A	10	5	5	10
	-423, level B	10	5	5	10
	-423 level C	10	5	5	10

[a] 2219 and 6061 aluminum alloys and 6Al-4V ELI titanium alloy were solution treated prior to straining; all other materials were strained in the as received condition.

[b] -110°F = 194°K; -320°F = 78°K; -423°F = 20°K

[c] The quantities listed are for heat treatable alloys. For nonheat treatable alloys, five specimens, rather than 10, were soaked or strained as indicated, they received no thermal treatment before being tested.

IV. TEST RESULTS AND DISCUSSION

Aluminum Alloy 2219

A sheet of annealed 2219 aluminum, measuring 0.080x48x144 in. (0.203x122 x366 cm) was procured to material specification ASTM B 209-67. The composition of the sheet was:

Element	Percent by weight
Cu	6.15
Mn	0.26
Mg	0.01
Si	0.07
Fe	0.17
Zn	0.03
Ti	0.06
V	0.08
Zr	0.13
Ni	0.01
Cr	0.01
Aℓ	Balance

Density: 0.103 lb/cu in.; 2.85 gm/cc

The 2219 aluminum specimens were prepared and processed generally as described in Chapter III. The procedures were modified somewhat for the 2219 aluminum alloy specimens, and also for the 6061 aluminum alloy specimens. The changes were necessary because these alloys will age harden at room temperature following solution heat treatment. This reaction, termed natural aging, can be withheld almost indefinitely if the material is refrigerated immeditely after it is quenched from the solution treatment temperature. As long as the material is held at or below 0°F (255°K) natural aging will not occur. Therefore, to compensate for the natural aging reaction and assure a unifrom starting condition for the 2219 specimens the following procedures were used.

1) The specimens were machined from the annealed sheet stock in the normal manner, as described in Chapter III;

2) The specimens were solution heat treated, 995°F (809°K) for 50 minutes, and quenched in cold water;

3) Immediately after quenching the specimens were refrigerated and stored at -30°F (239°K);

4) The specimens that were either tested at room temperature to establish the material's room temperature uniform strain capability or strained at room temperature, were removed from the refrigerator and immediately immersed in water that was at room temperature. Within 15 minutes from the time that the temperature of a specimen reached room temperature the specimen was tested, or strained. The strained specimens were then naturally aged at room temperature for a minimum of seven days before they were further processed in the normal manner, as described in Chapter III;

5) The specimens that were not strained at room temperature, but merely exposed to room temperature, were removed from the refrigerator, warmed to room temperature, naturally aged at room temperature for a minimum of seven days, and then processed in the normal manner;

6) The specimens that were tested, strained, or exposed at any of the cyrogenic temperatures were kept under refrigeration until they were placed in a cryostat and immersed in the appropriate cryogen. The specimens that had been cryostrained or exposed to a cryogenic temperature were then warmed to room temperature and naturally aged at room temperature for a minimum of seven days before being processed in the normal manner.

When 2219 is cold worked after it has been solution heat treated and quenched and before it is aged the rate of strengthening during the aging treatment is markedly increased. Consequently, highly strained material should be aged at lower temperatures and for shorter periods of time than unstrained material. Therefore, the 2219 aluminum alloy specimens that had to be aged were given one of the following aging treatments, as indicated.

1) The unstrained specimens were aged for 36 hr at 375°F (465°K) and air cooled;

2) Of each group of five specimens that had been given the same conditioning treatment (strained the same amount at the same temperature) four were aged 24 hr at 325°F (436°K) and air cooled;

3) The rest of the strained specimens were aged 18 hr at 325°F (436°K) and air cooled.

The results of the tests conducted on the 2219 aluminum alloy specimens are given in figures 6 through 14, and are listed in tables 2 and 3 of the Appendix. Figure 15 shows photomicrographs of the microstructure of 2219 in various conditions.

The 2219 aluminum alloy sheet was found to have a uniform strain capability of 21.0% at room temperature, 18.0% at -110°F (194°K), 35% at -320°F (78°K), and 36% at -423°F (20°K). However, the apparent advantage of a higher uniform strain capability at -320°F (78°K) and -423°F (20°K) than at room temperature proved to be of no significant value. While 2219 specimens were strained greater amounts at both -320°F (78°K) and -423°F (20°K) than at room temperature, the room temperature straining was almost as effective a strengthening process as straining at either of the cryogenic temperatures.

Thus, cryostraining is not a practical method for strengthening 2219 aluminum.

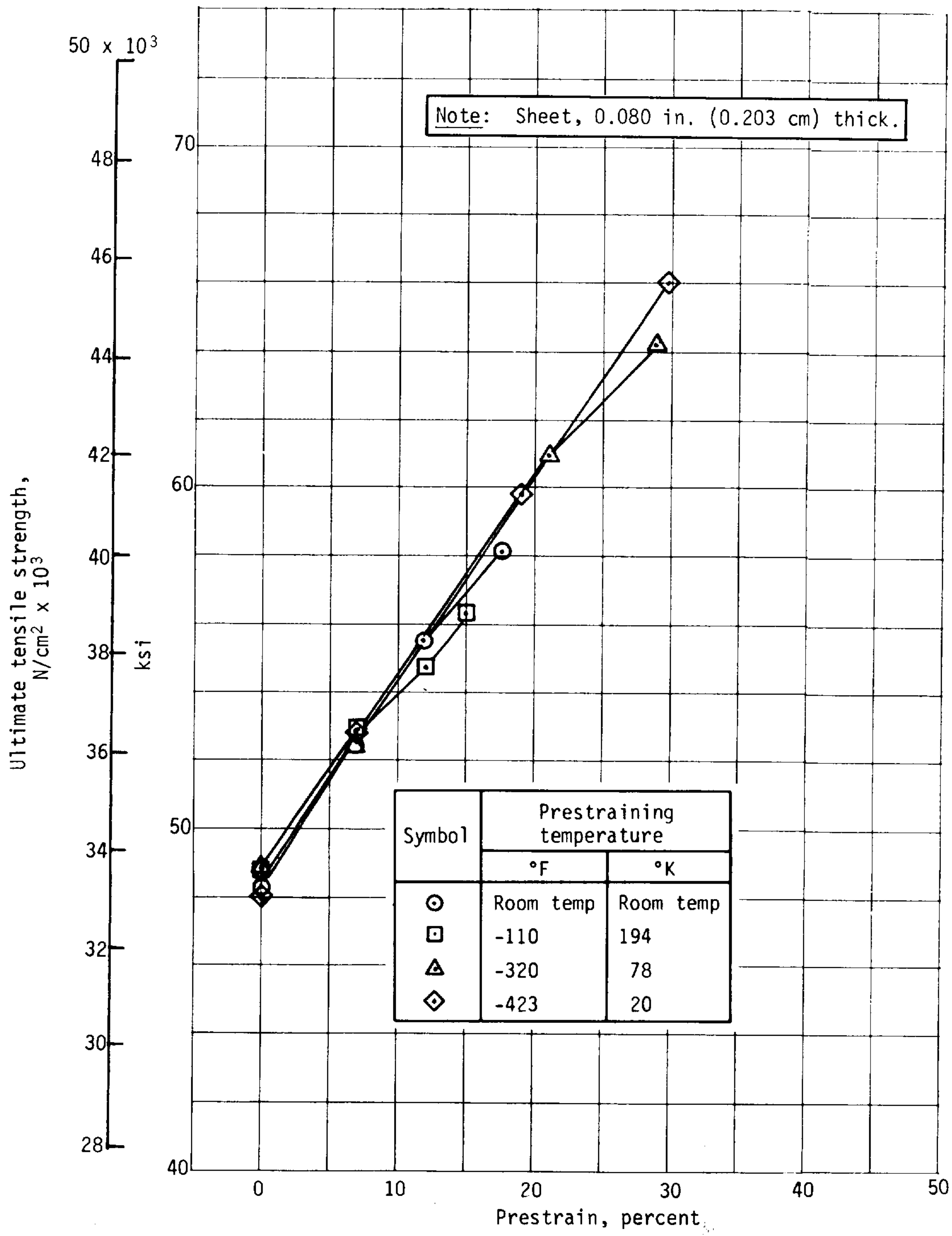


Figure 6.- Ultimate Tensile Strength of Prestrained 2219 Aluminum Alloy

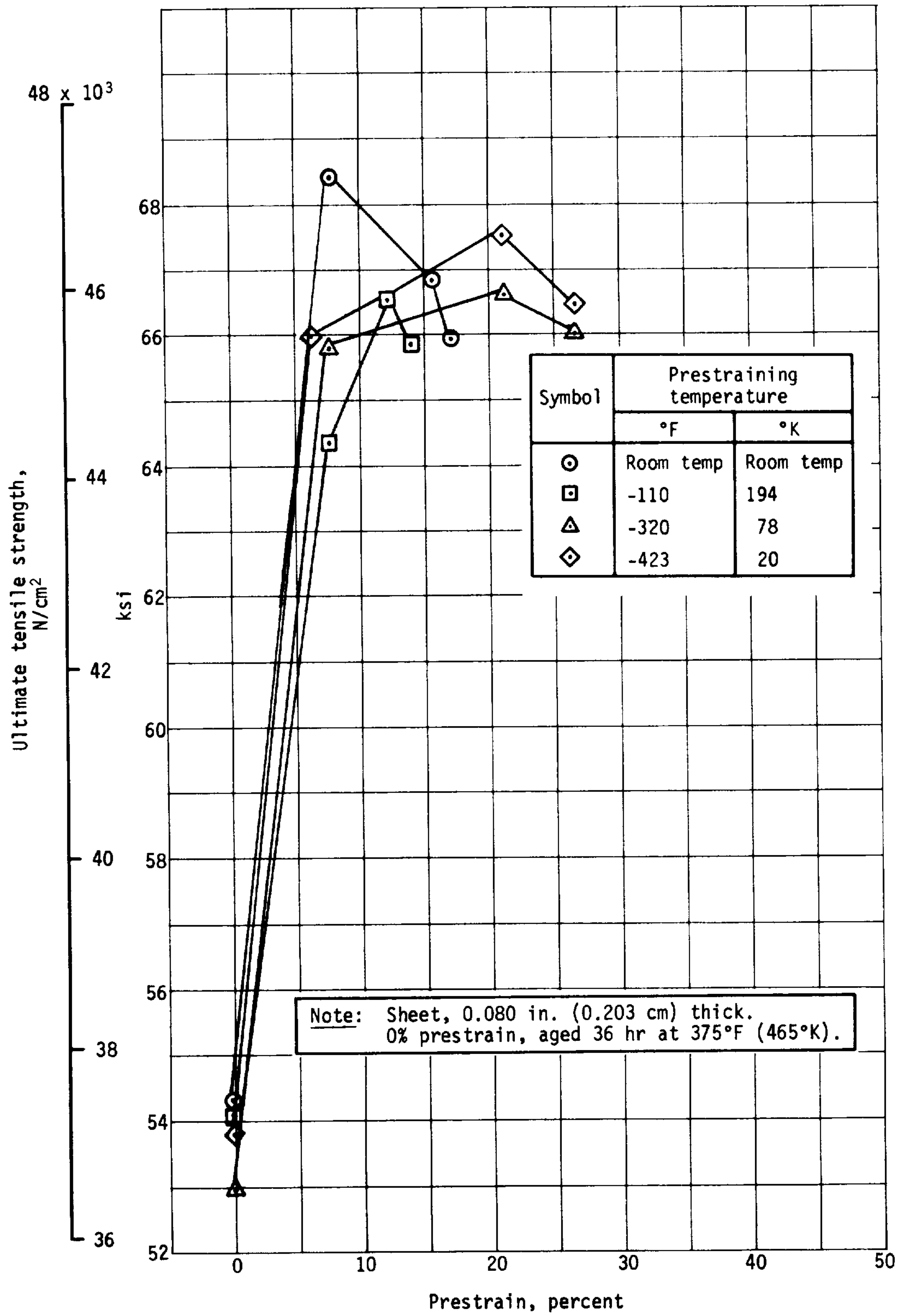


Figure 7.- Ultimate Tensile Strength of Prestrained 2219 Aluminum Alloy, Aged 18 hr at 325°F (436°K)

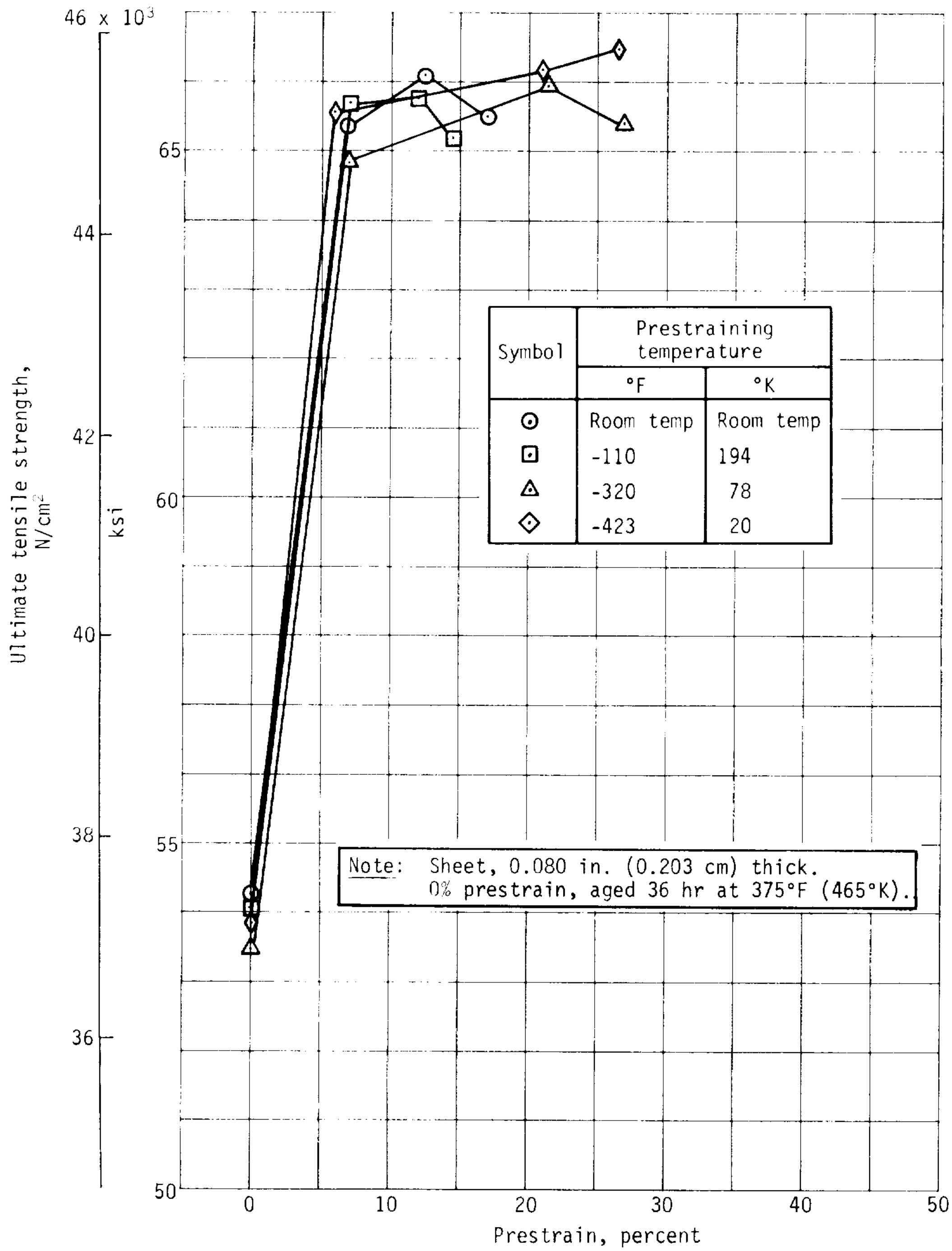


Figure 8.- Ultimate Tensile Strength of Prestrained 2219 Aluminum Alloy, Aged 24 hr at 325°F (436°K)

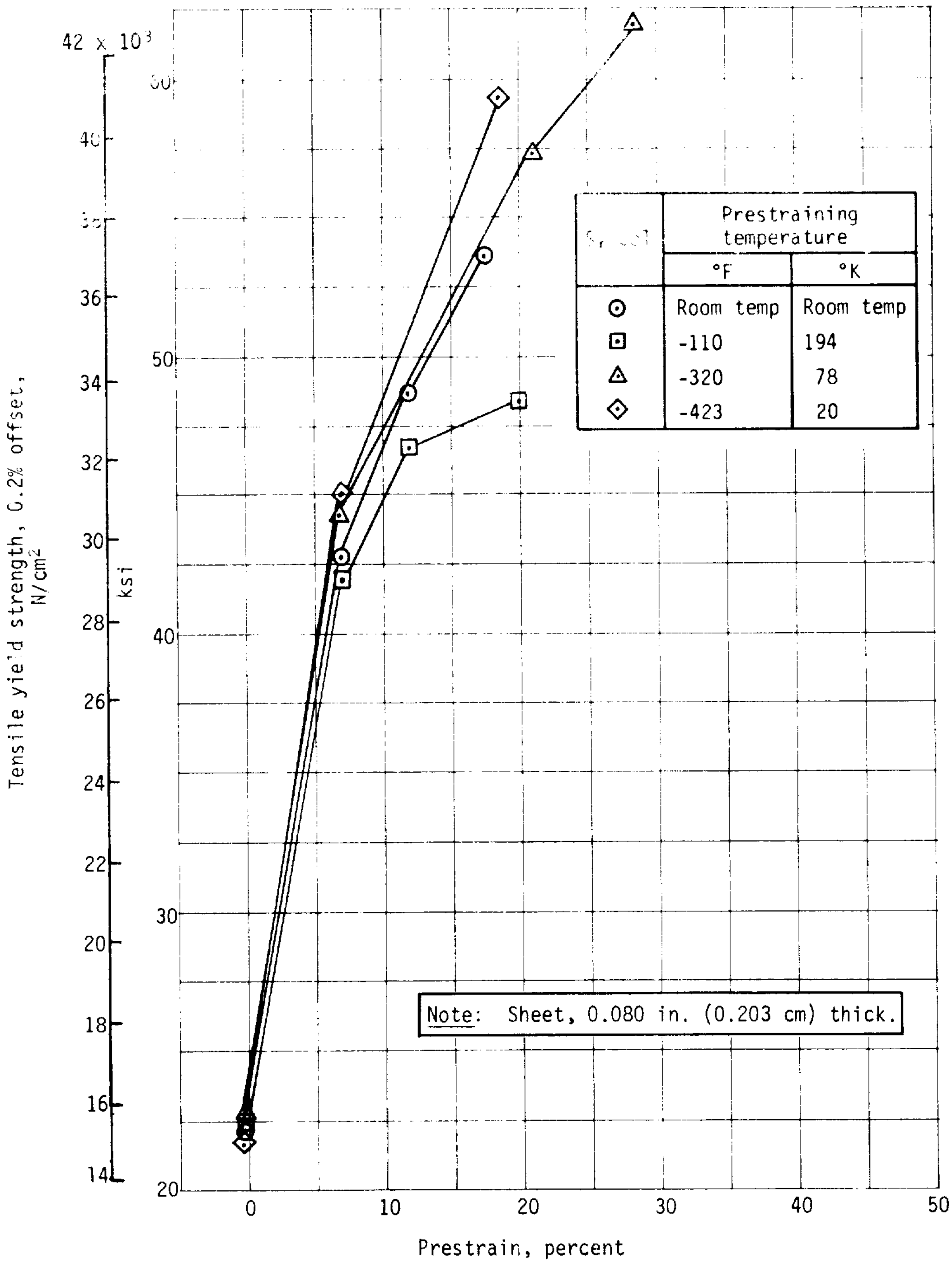


Figure 9.- Tensile Yield Strength of Prestrained 2219 Aluminum Alloy

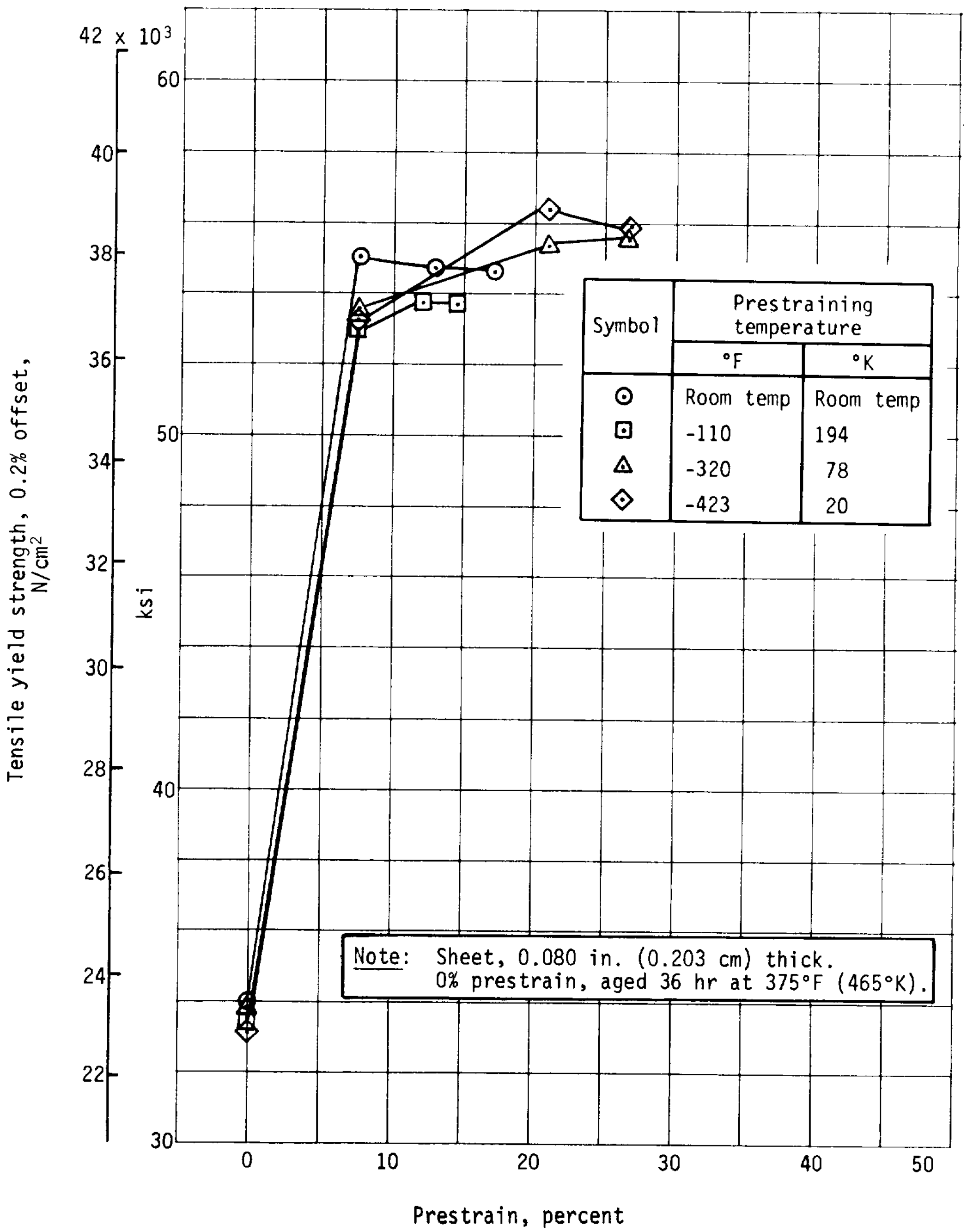


Figure 10.- Tensile Yield Strength of Prestrained 2219 Aluminum Alloy, Aged 18 hr at 325°F (436°K)

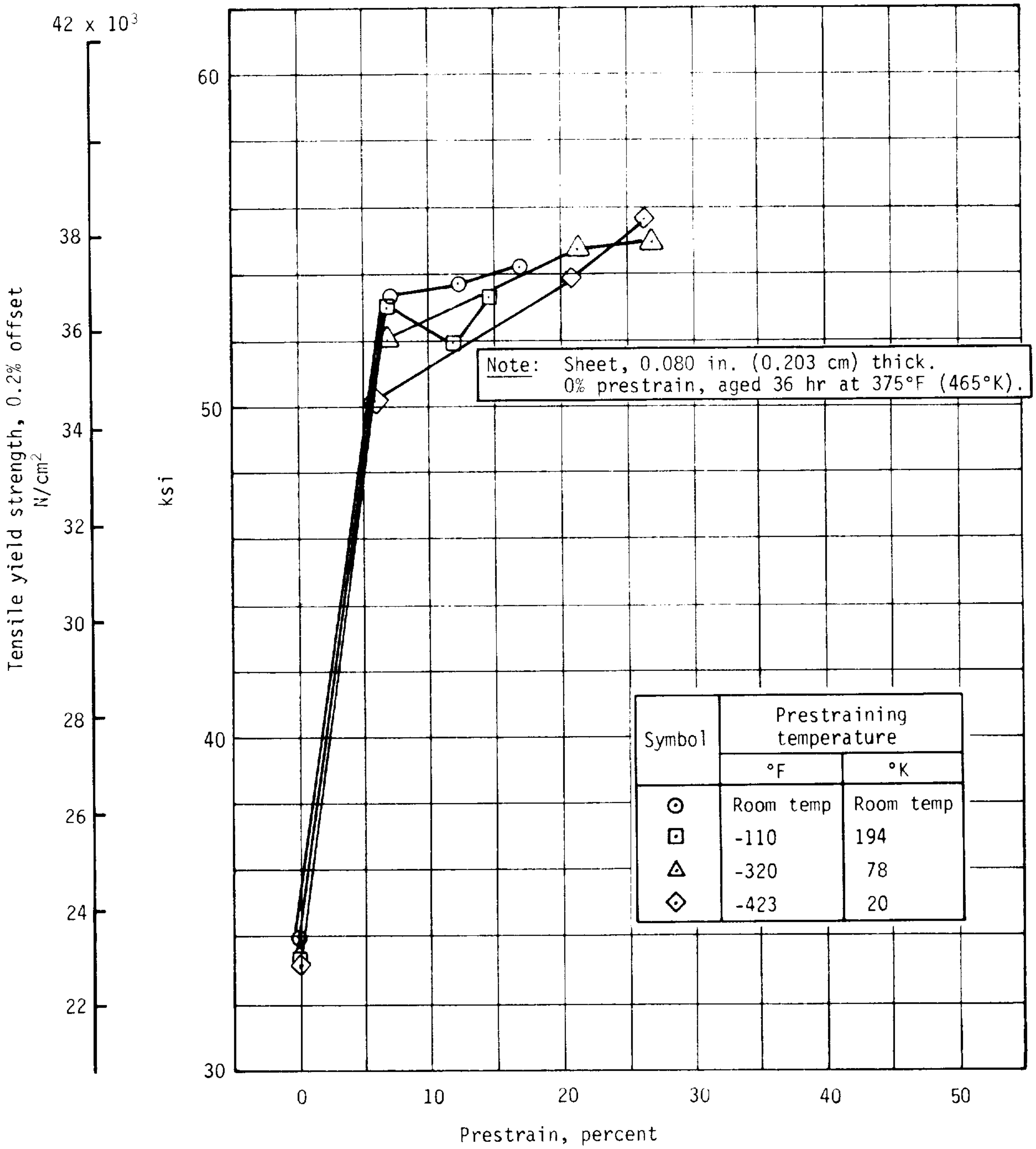


Figure 11.- Tensile Yield Strength of Prestrained 2219 Aluminum Alloy, Aged 24 hr at 325°F (436°K)

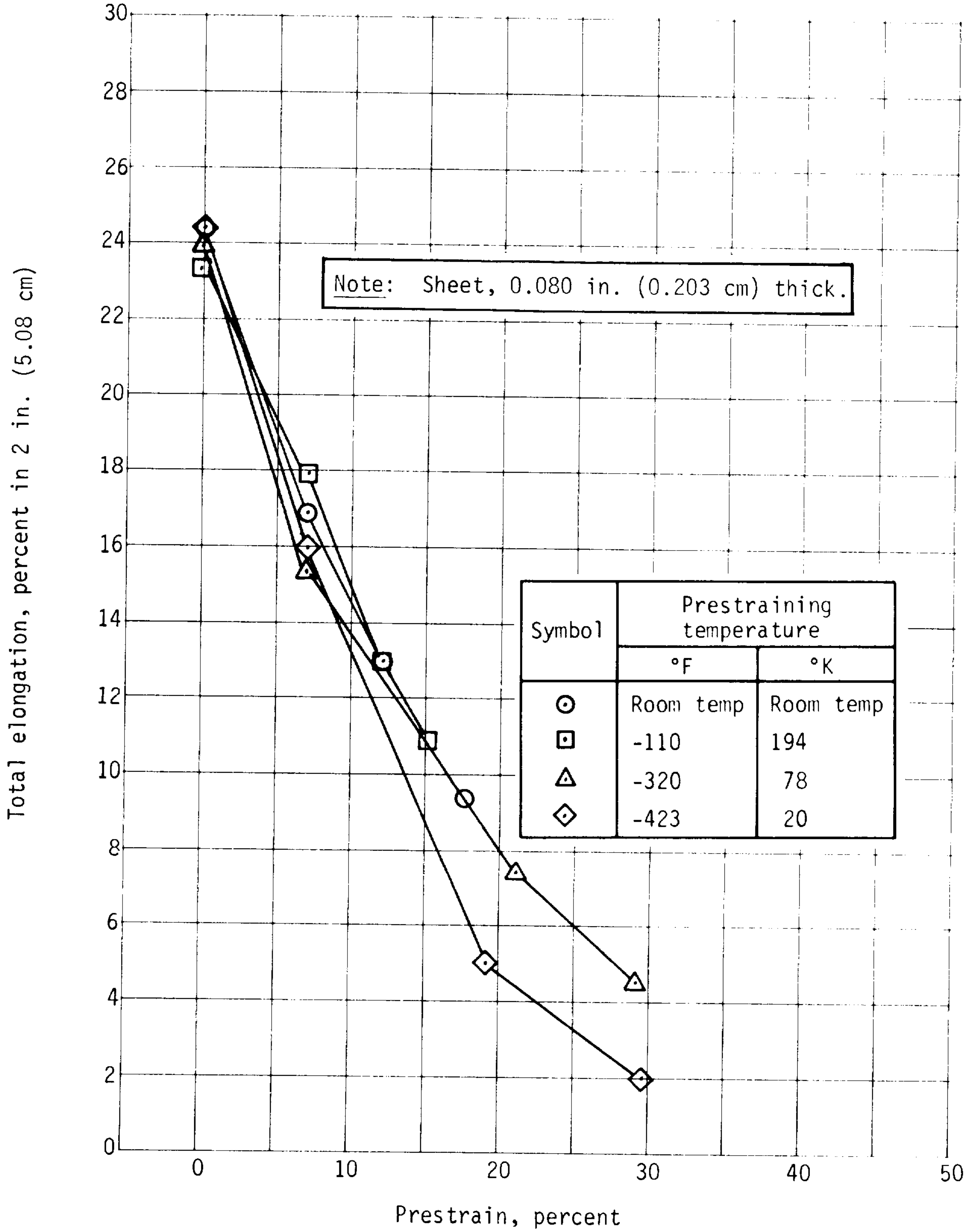


Figure 12.- Total Elongation of Prestrained 2219 Aluminum Alloy

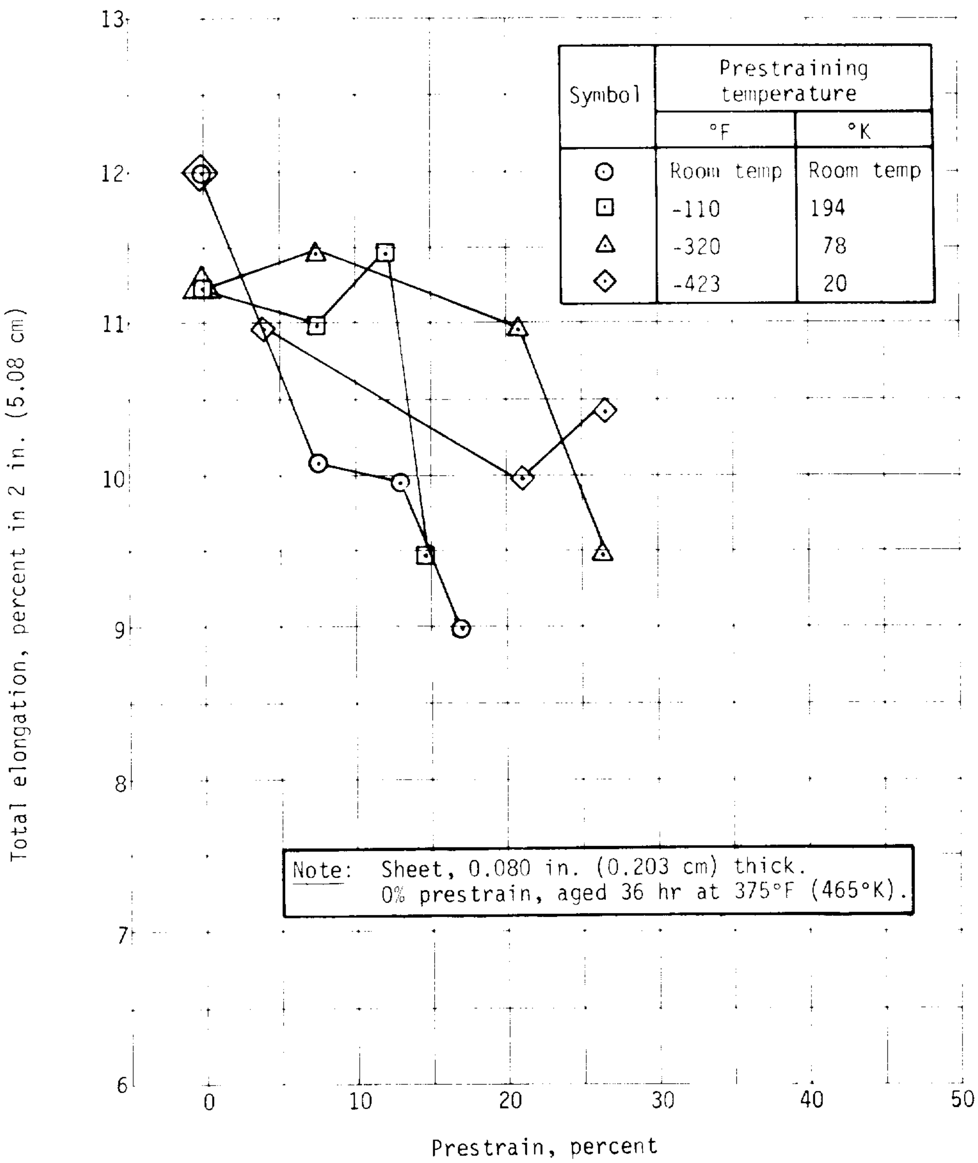


Figure 13.- Total Elongation of Prestrained 2219 Aluminum Alloy, Aged 18 hr at 325°F (436°K)

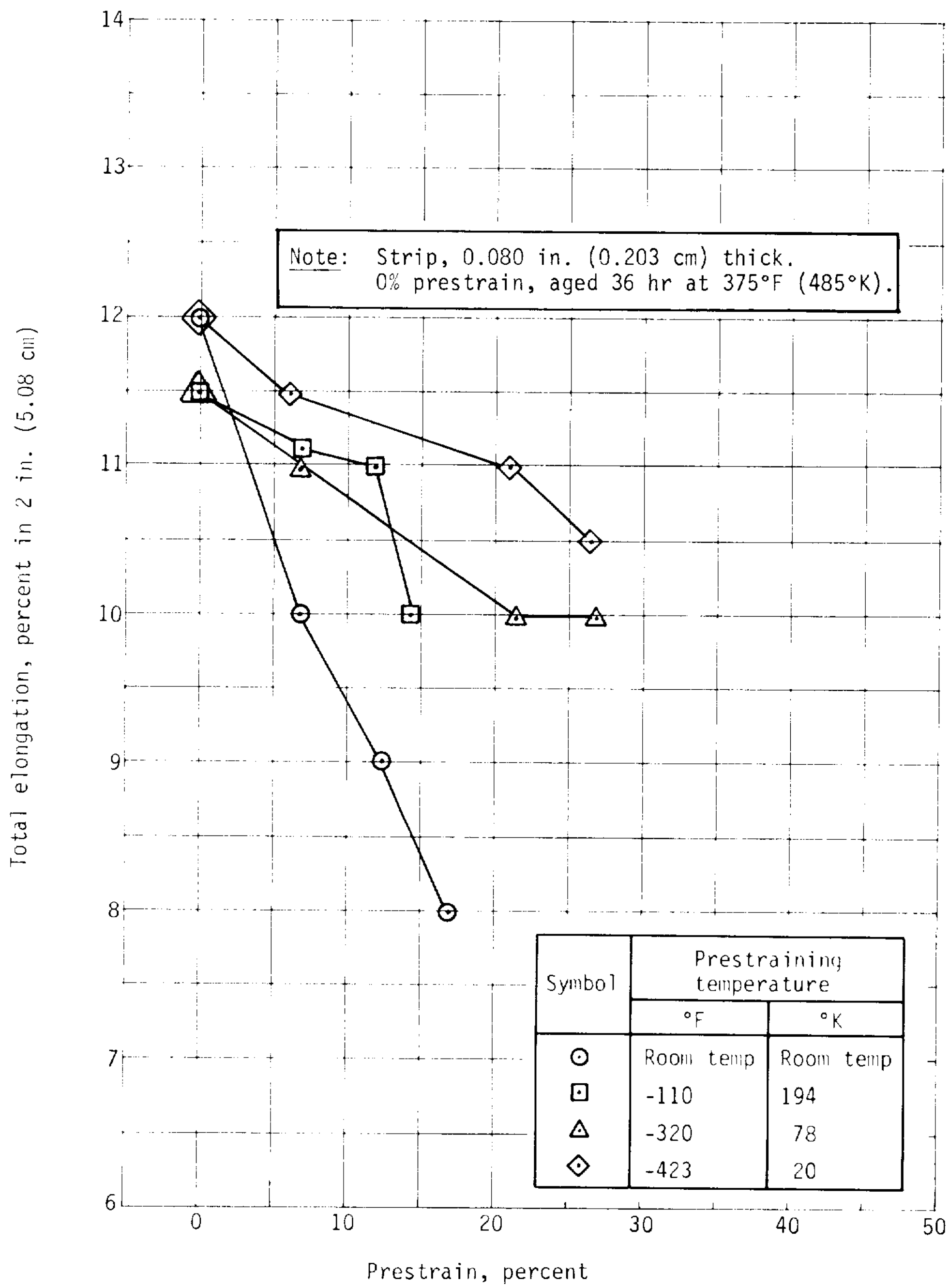
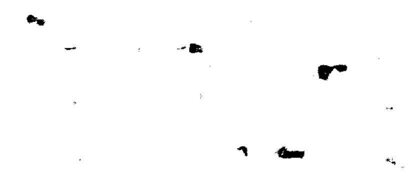


Figure 14.- Total Elongation of Prestrained 2219 Aluminum Alloy, Aged 24 hr at 325°F (436°K).



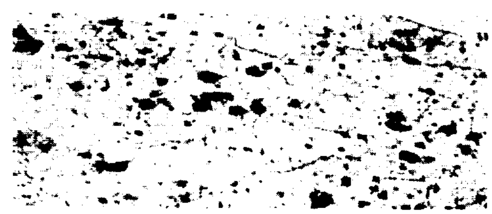
(a) Soaked at Room Temperature, Unaged

(b) Soaked at Room Temperature, aged 36 hr at 375°F (465°K)

(c) 17.0% Strain at Room Temperature, Aged 18 hr at 325°F (436°K)

(d) 14.0% Strain at -110°F (194°K), Aged 18 hr at 325°F (436°K)

(e) 28.0% Strain at -320°F (78°K), Aged 24 hr at 325°F (436°K)



(f) 29.0% Strain at -423°F (20°K), Aged 24 hr at 325°F (436°K)

Note:	There were no apparent changes to the microstructure due to straining at different temperatures.

Etch: Kellers 250X

Figure 15.- Microstructure of 2219 Aluminum Alloy

Aluminum Alloy 5456

A sheet of annealed 5456 aluminum was procured to commercial requirements. The sheet measured 0.063x48x144 in. (0.160x122x366 cm). An analysis was conducted and the chemical composition of the sheet was determined to be:

Element	Percent by weight
Mg	4.80
Mn	0.50
Si	0.09
Ni	0.01
Cr	0.12
Cu	0.03
Fe	0.12
Ti	0.02
Zr	0.11
Aℓ	Balance

Density: 0.096 lb/cu in.; 2.66 gm/cc

This alloy belongs to the 5XXX series of aluminum alloys. Unlike the 2219 and 6061 aluminum alloys, 5456 is strengthened by strain hardening, but not by thermal treatment. Consequently, special processes, such as refrigeration, were not required for the 5456 specimens. They were processed in the normal manner as described in Chapter III.

The results of the test conducted on the 5456 aluminum alloy sheet specimens are given in figures 16 through 18, and are listed in tables 4 and 5 of the Appendix. Figure 19 shows photomicrographs of the microstructure of 5456 in various conditions.

The 5456 aluminum alloy sheet has a higher uniform strain capability at the cryogenic temperatures than at room temperature; specifically, 19.5% at room temperature, 25.0% at -110°F (194°K), 40% at -320°F (78°K), and 22% at -423°F (20°K). Therefore, it is possible to work this strain-hardening alloy to higher strengths at the cryogenic temperatures than at room temperature. This is the only advantage that can be gained from cryostraining 5456 aluminum alloy sheet, and this advantage is of questionable value. Other aluminum alloys of the 2XXX and 7XXX series processed by conventional methods develop strengths greater than the strengths that can be developed by cryostraining 5456. Also, 5456 is available in various strain hardened tempers, one such is the -H343 temper. The following tabulation lists the typical tensile properties of 5456-H343 sheet and the room temperature tensile properties of 5456-0 after it was strained 31.5% at -323°F (78°K).

Property	5456-H343		5456-0 Strained 31.5%	
	Psi	N/cm^2	Psi	N/cm^2
Ultimate tensile strength	63 000	43 400	63 300	43 600
Tensile yield strength, 0.2% offset	51 000	35 200	59 300	40 900
Percent elongation in 2 in. (5.08 cm)	6.0	6.0	4.5	4.5

All factors considered, cryostraining is not a practical method of strengthening 5456 aluminum.

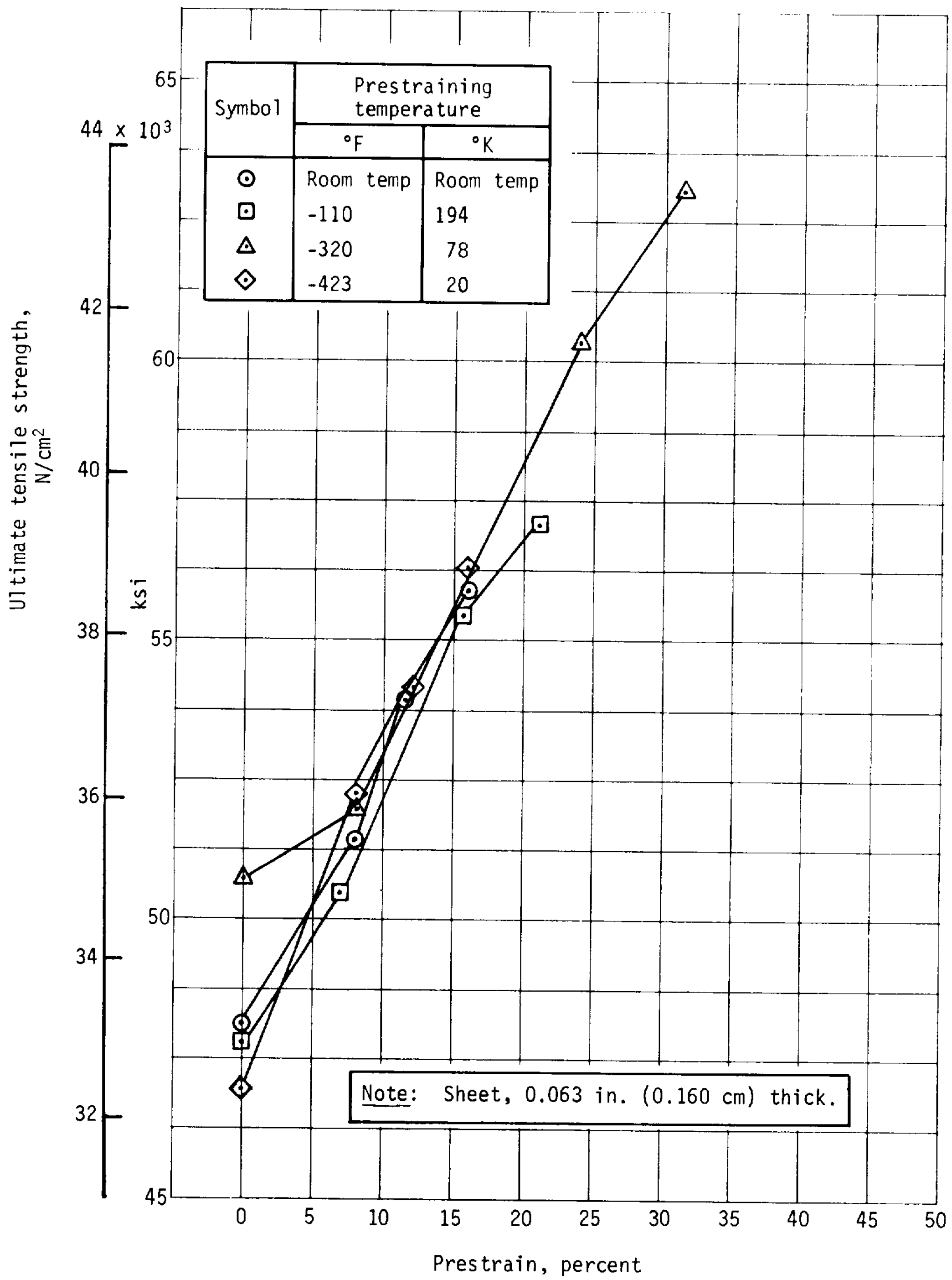


Figure 16.- Ultimate Tensile Strength of Prestrained 5456 Aluminum Alloy

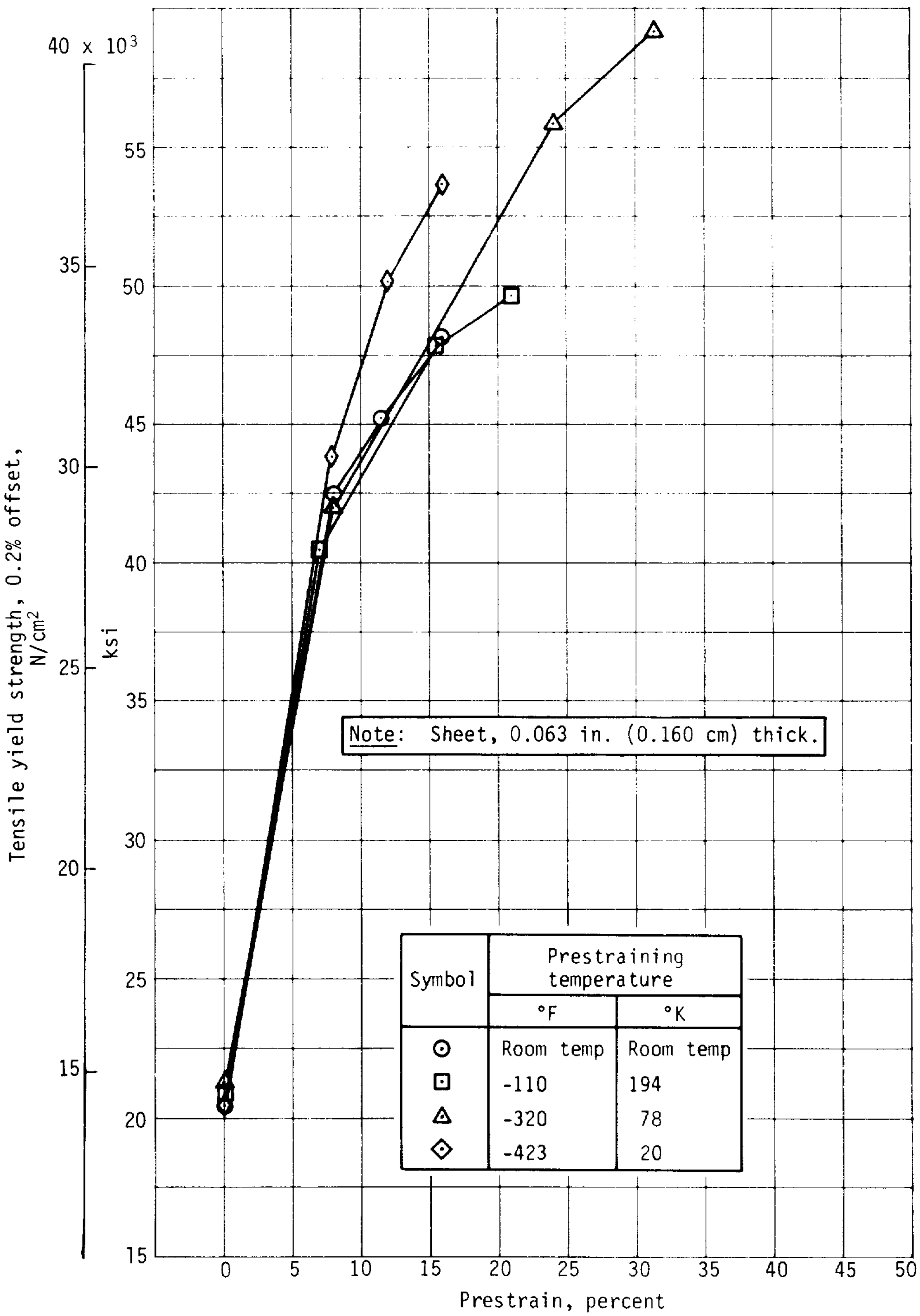


Figure 17.- Tensile Yield Strength of Prestrained 5456 Aluminum Alloy

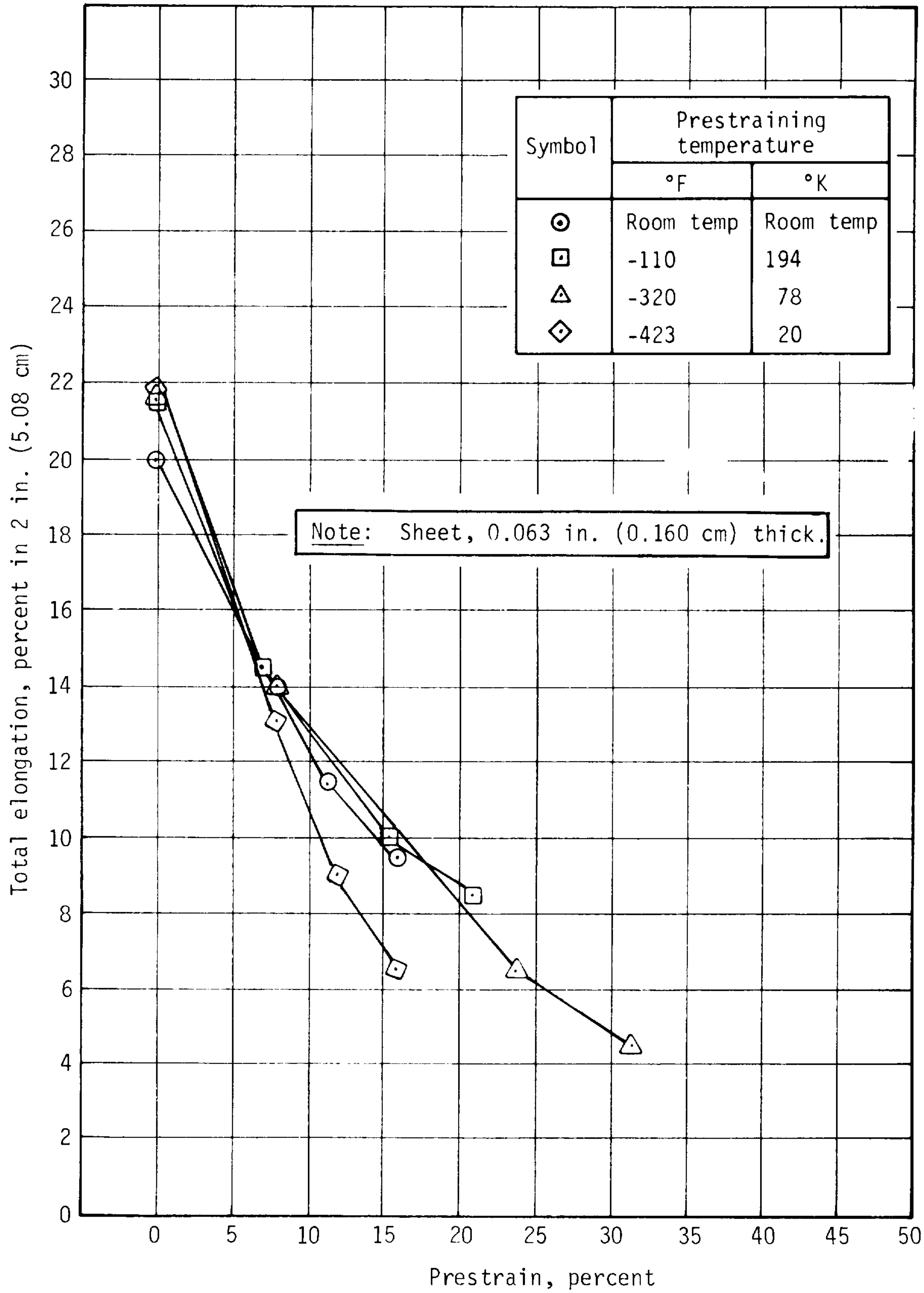
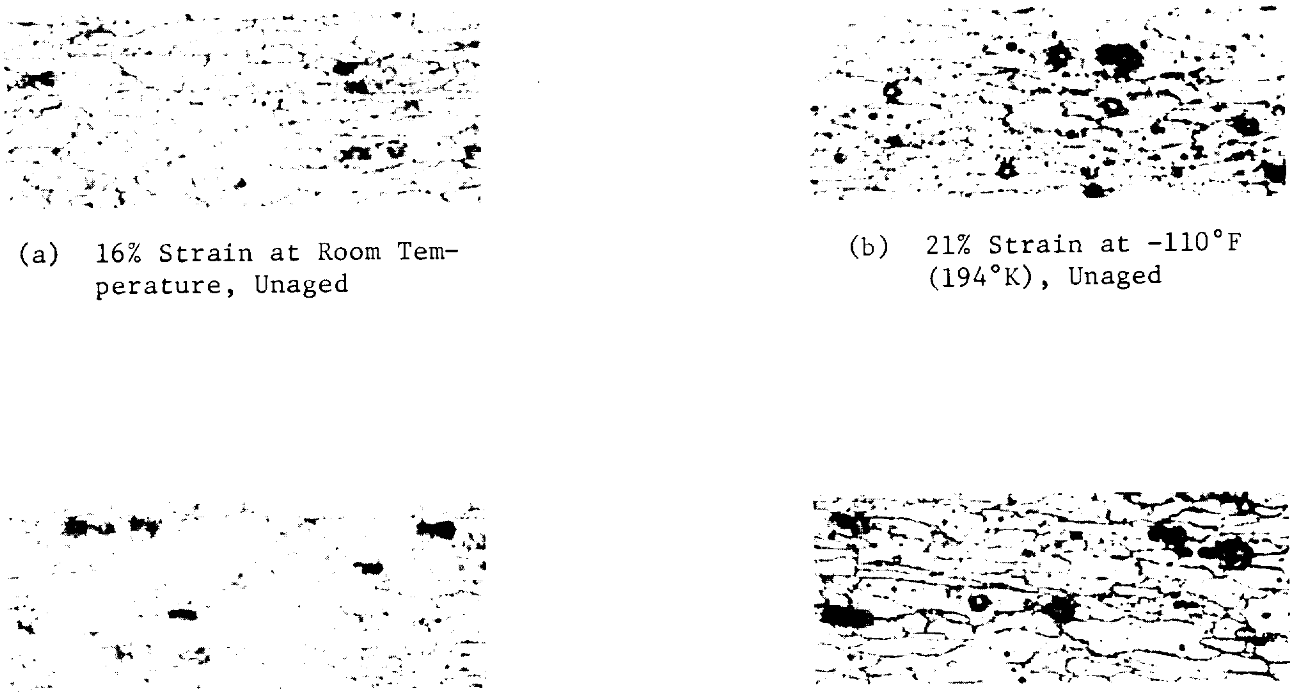


Figure 18.- Total Elongation of Prestrained 5456 Aluminum Alloy



(a) 16% Strain at Room Temperature, Unaged

(b) 21% Strain at -110°F (194°K), Unaged

(c) 31.5% Strain at -320°F (78°K), Unaged

(d) 16% Strain at -423°F (20°K), Unaged

<u>Note</u>:	The effects of straining at different temperatures are not manifest by observable changes to the microstructure.

Etch: Kellers

200X

Figure 19.- Microstructure of 5456 Aluminum Alloy

Aluminum Alloy 6061

A sheet of annealed 6061 aluminum measuring 0.090x48x48 in (0.229x122x122 cm) was procured to Federal Specification QQ-A-250/11. The chemical composition of the sheet was:

Element	Percent by weight
Mg	0.82
Si	0.66
Fe	0.45
Cu	0.26
Mn	0.01
Cr	0.19
Zn	0.12
Ti	0.01
Ni	0.01
Aℓ	Balance

Density: 0.098 lb/cu in.; 2.71 gm/cc

The 6061 aluminum specimens were prepared and processed generally as described in Chapter III. The procedures were modified somewhat for the 6061 aluminum alloy specimens, and also for the 2219 aluminum alloy specimens. The changes were necessary because these alloys will age harden at room temperature following solution heat treatment. This reaction, termed natural aging, can be withheld almost indefinitely if the material is refrigerated immediately after it is quenched from the solution treatment temperature. As long as the material is held at or below 0°F (255°K) natural aging will not occur. Therefore, to compensate for the natural aging reaction and assure a uniform starting condition for the 6061 specimens the following procedures were used:

1) The specimens were machined from the annealed sheet stock in the normal manner, as described in Chapter III;

2) The specimens were solution heat treated, 980°F (800°F) for 1 hr, and quenched in cold water;

3) Immediately after quenching, the specimens were refrigerated and stored at -30°F (239°K);

4) The specimens that were either tested at room temperature to establish the material's room temperature uniform strain capability or strained at room temperature, were removed from the refrigerator and immediately immersed in water that was at room temperature. Within 15 minutes from the time that the temperature of a specimen reached room temperature the specimen was tested or strained. The strained specimens were then naturally aged at room temperature for a minimum of seven days before they were further processed in the normal manner, as described in Chapter III;

5) The specimens that were not strained at room temperature, but merely exposed to room temperature, were warmed to room temperature, naturally aged at room temperature for a minimum of seven days, and then processed in the normal manner;

6) The specimens that were tested, strained, or exposed at any of the cryogenic temperatures were kept under refrigeration until they were placed in a cryostat and immersed in the appropriate cryogen. The specimens that had been cryostrained or exposed to a cryogenic temperature were then warmed to room temperature and naturally aged at room temperature for a minimum of seven days before being processed in the normal manner.

The results of the tests conducted on the 6061 aluminum alloy specimens are given in figures 20 through 25, and in the Appendix, tables 6 and 7. Figure 26 shows photomicrographs of the microstructure of 6061 in various conditions.

The uniform strain capability of the 6061 sheet material was found to be essentially the same at room temperature and at -110°F (194°K), 21 and 22%, respectively. But at -320°F (78°K) and at -423°F (20°K) the uniform strain capability was 42 and 43%, respectively, almost double the material's room temperature capability. Therefore, since the 6061 sheet material did strain harden, higher strengths were developed by straining at -320°F (78°K) and at -423°F (20°K) than by straining at room temperature. This was only because the material was strained greater amounts at the lower temperatures. It was the magnitude of the strain that determined the properties developed by straining; strengthening was independent of straining temperature. For example, an 8.5% strain developed essentially the same tensile properties regardless of the temperature at which the 6061 was strained.

By making use of the increased uniform strain capability of 6061 at -320°F (78°K) appreciably higher tensile strengths were developed at those temperatures than at room temperature. Tensile strengths greater than 50 000 psi (34 480 N/cm^2) were achieved at both cryogenic temperatures, but such strengthening does not justify cryostraining 6061. Other aluminum alloys in the 2xxx and 7xxx series of aluminum alloys develop even higher strengths through normal processing. Therefore, although 6061 can be strengthened by cryostraining, such processing is not practical.

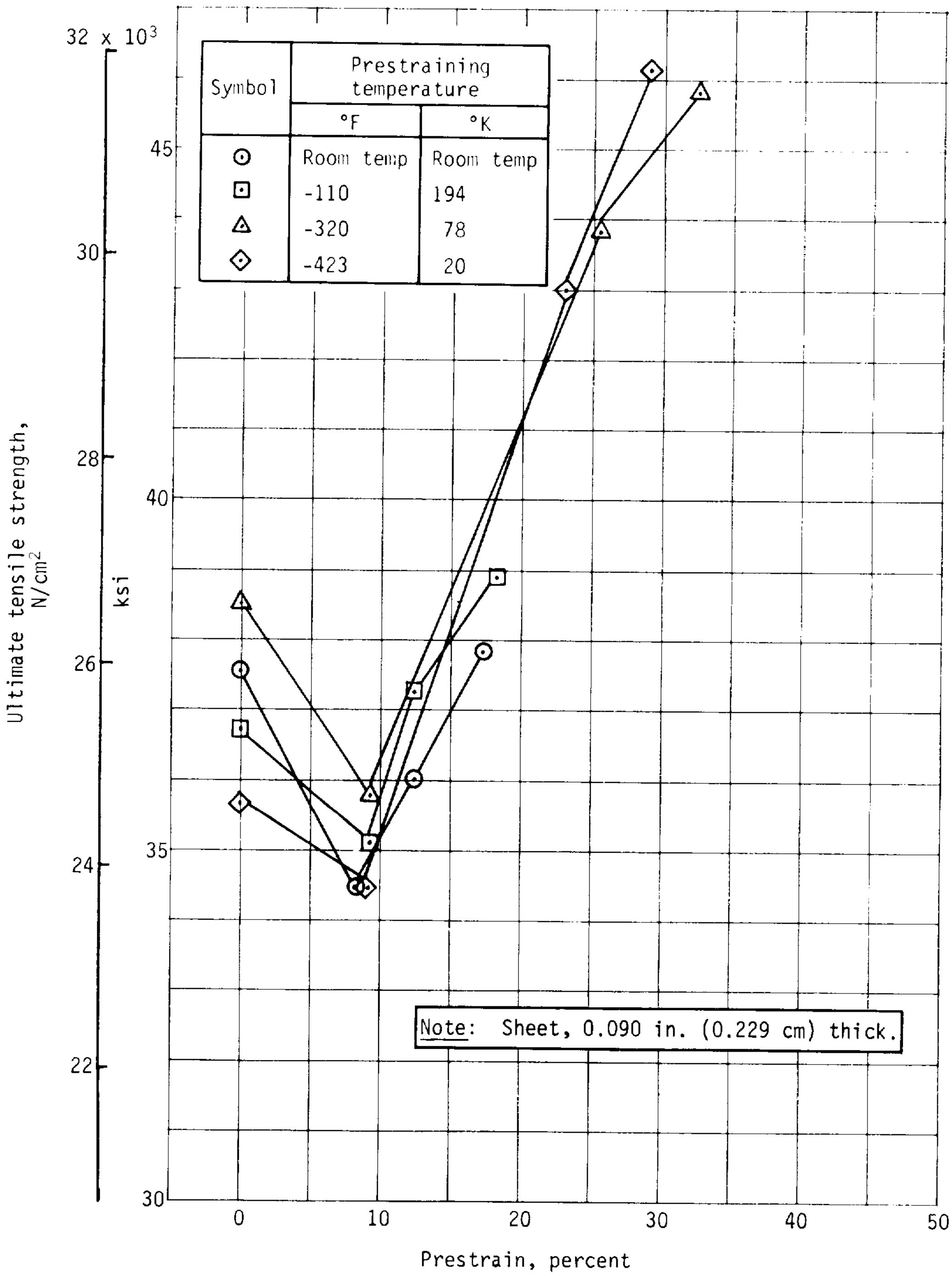


Figure 20.- Ultimate Tensile Strength of Prestrained 6061 Aluminum Alloy

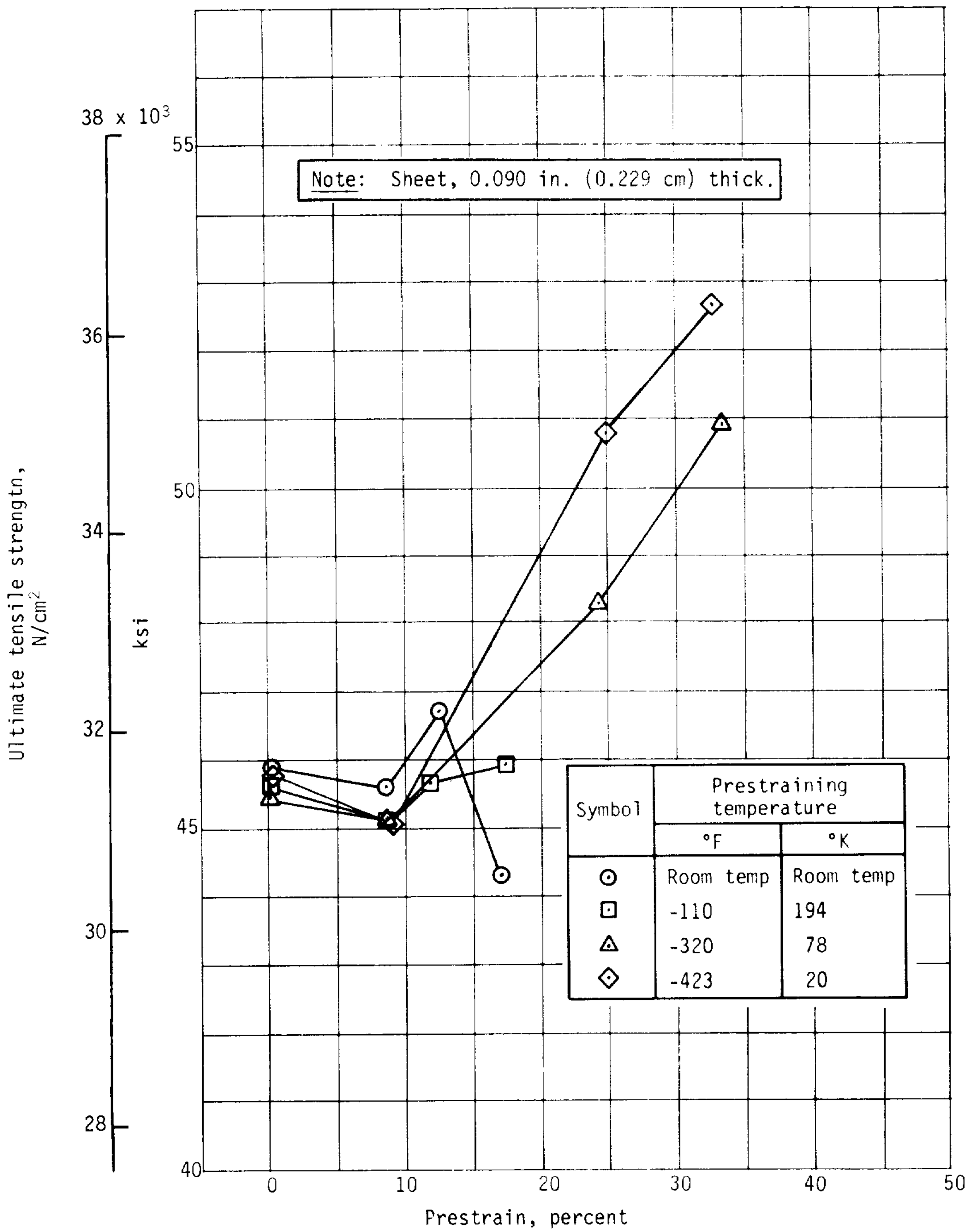


Figure 21.- Ultimate Tensile Strength of Prestrained 6061 Aluminum Alloy, Aged 16 hr at 320°F (434°K)

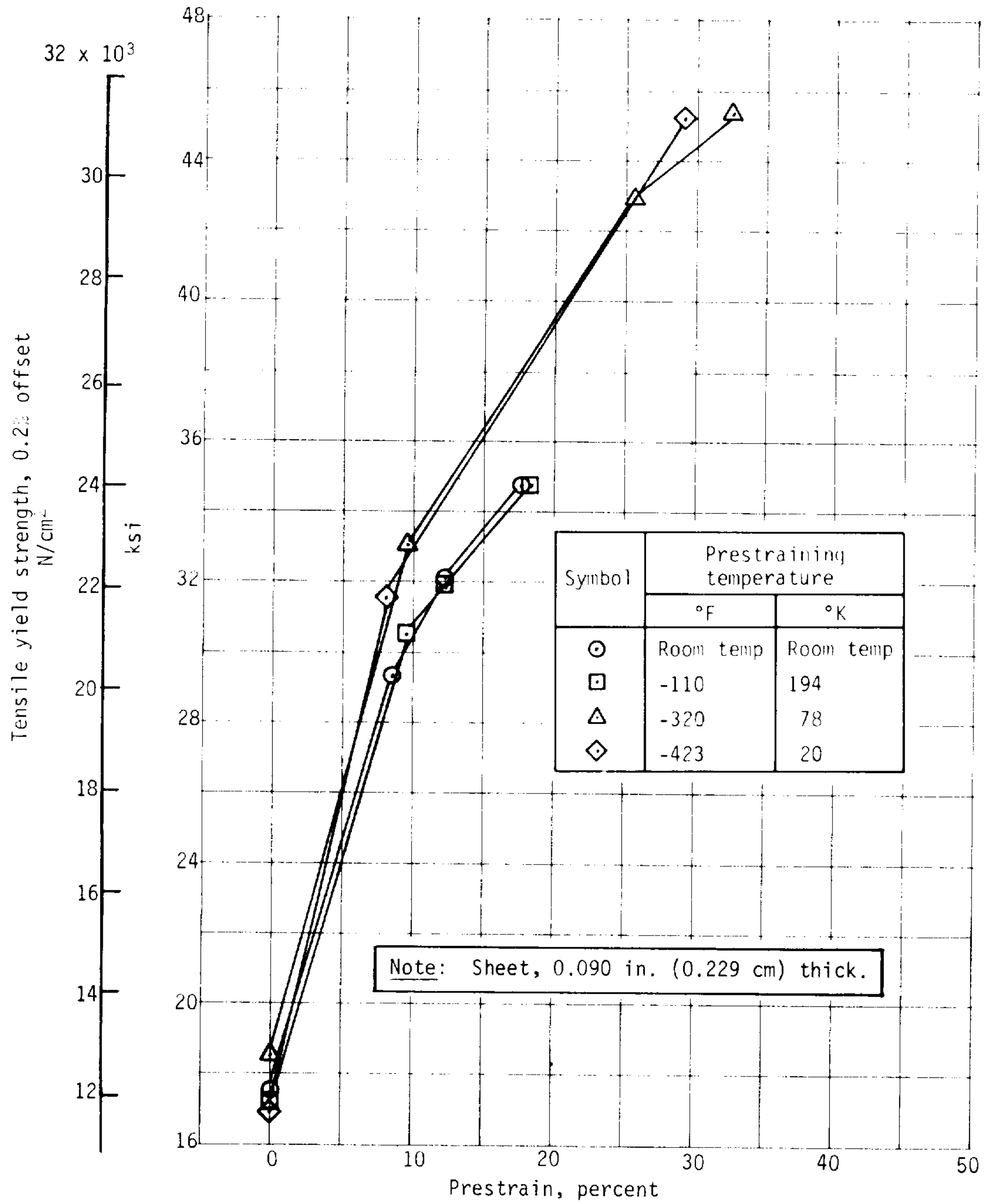


Figure 22.- Tensile Yield Strength of Prestrained 6061 Aluminum Alloy

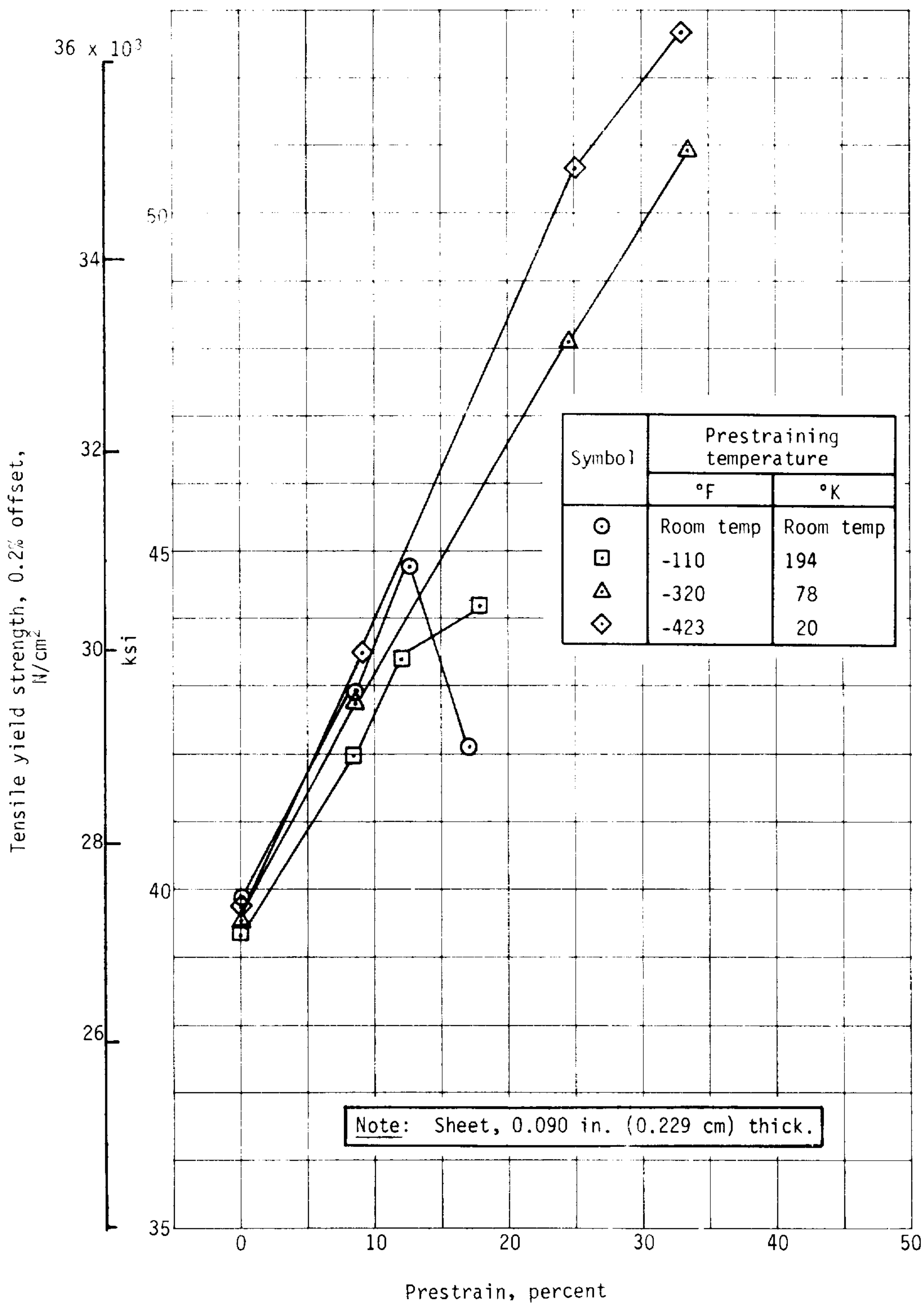


Figure 23.- Tensile Yield Strength of Prestrained 6061 Aluminum Alloy, Aged 16 hr at 320°F (434°K)

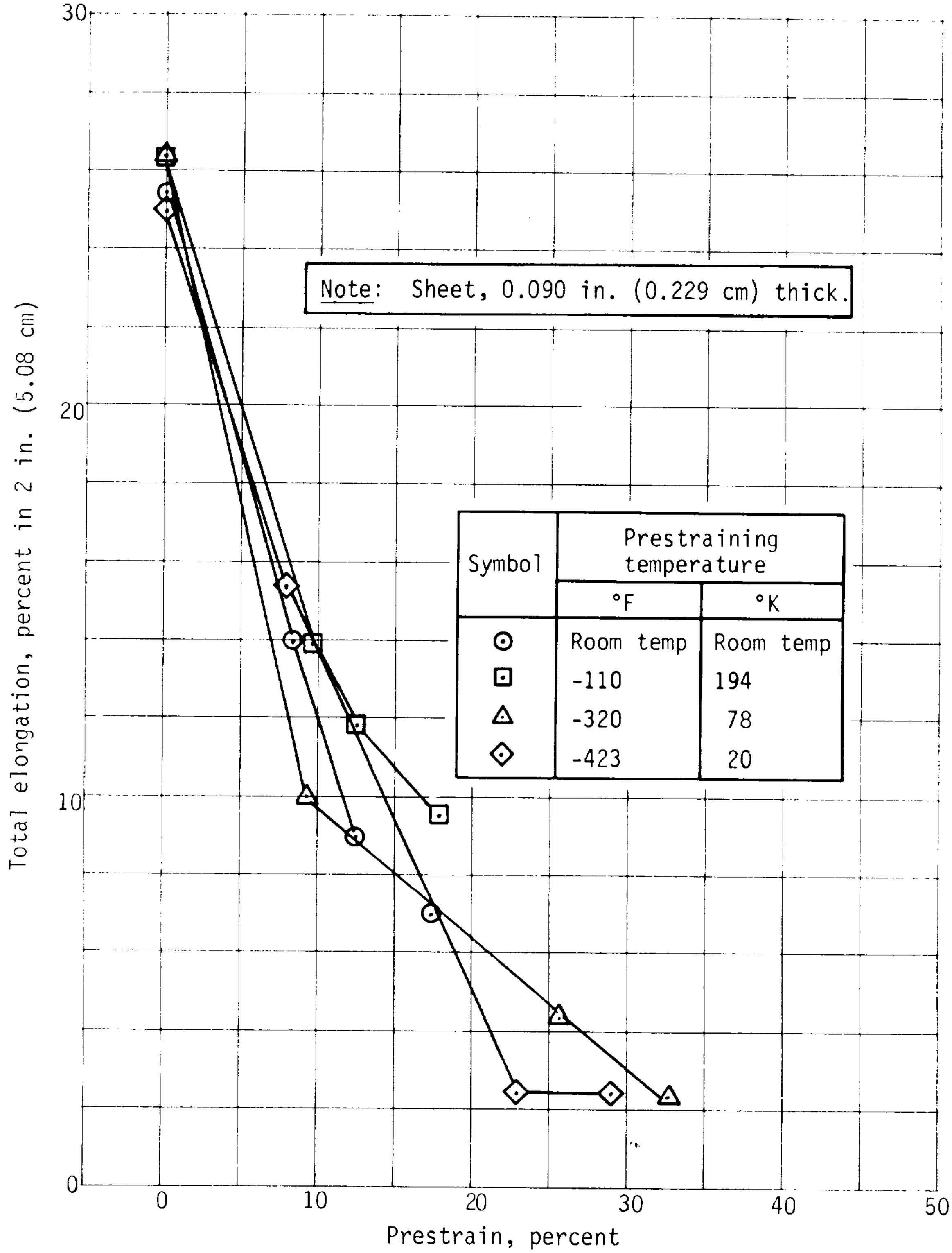
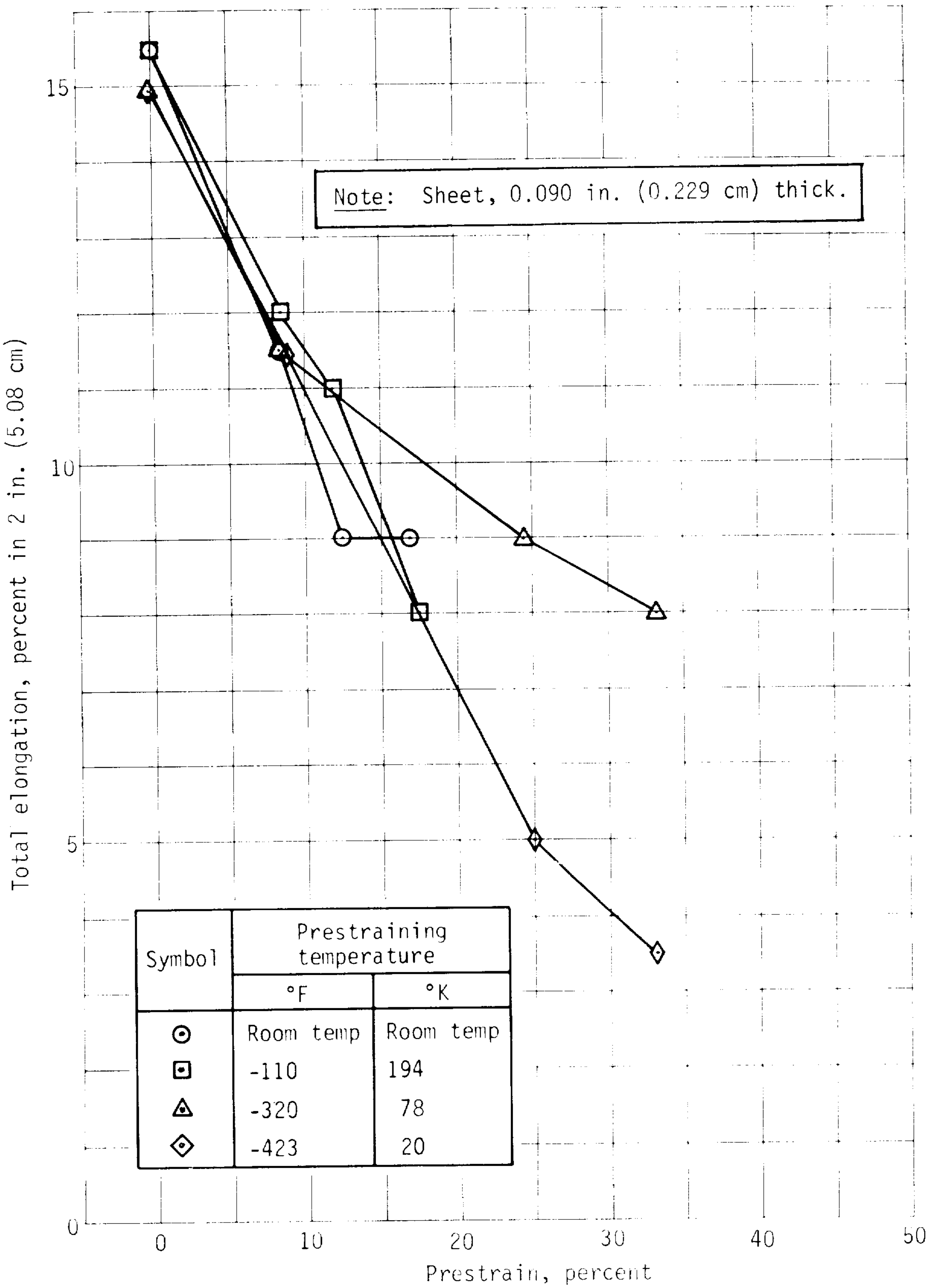


Figure 24.- Total Elongation of Prestrained 6061 Aluminum Alloy



Symbol	Prestraining temperature, °F	Prestraining temperature, °K
⊙	Room temp	Room temp
⊡	-110	194
△	-320	78
◇	-423	20

Figure 25.- Total Elongation of Prestrained 6061 Aluminum Alloy, Aged 16 hr at 320°F (434°K)

(a) 17% Strain at Room Temperature, Aged 18 hr at 320°F (434°K)

(b) Soaked at -110°F (194°K), Aged 18 hr at 320°F (434°K)

(c) Strain at -110°F (194°K), Aged 18 hr at 320°F (434°K)

(d) Soaked at -320°F (78°K), Aged 18 hr at 320°F (434°K)

(e) Strain at -320°F (78°K), Aged 18 hr at 320°F (434°K)

(f) Soaked at -423°F (70°K), Aged 18 hr at 320°F (434°K)

Note: The microstructure was not significantly changed by straining at different temperatures. The more evident strain lines in (a), (c), and (d) are due to the tensile test rather than the pre-age straining operation. They show structure near the fractures. Photos (b), (e), and (f) show structure farther from the fracture.

Etch: Kellers

200X

Figure 26.- Microstructure of 6061 Aluminum Alloy

Beryllium Copper (CDA 172)

Six strips of annealed stock, measuring 0.050x7.25x72 in. (0.127x18.42x 183 cm) were procured to Federal Specification QQ-C-533. The chemical composition of the strip material was:

Element	Percent by weight
Be	1.76
Fe	0.01
Co	0.24
Cu	Balance

Density: 0.297 lb/cu in; 8.23 gm/cc

This copper alloy, Copper Development Association No. 172, is known commercially as beryllium copper. It is an age hardening material that has excellent forming characteristics in the annealed condition. After aging it has excellent fatigue and hysteresis properties, a high proportional limit, and is highly creep resistant.

The beryllium copper specimens were prepared and processed in the normal manner, as described in Chapter III. The specimens requiring thermal treatment were aged for 3 hr at 600°F (589°K).

The results of the tests conducted on the beryllium copper alloy specimens are presented in figures 27 thru 32, and are listed in tables 8 and 9 of the Appendix. Photomicrographs of the microstructure of this material after various treatments are shown in figure 33.

The beryllium copper strip material was found to have a higher uniform strain capability at the cryogenic temperatures than at room temperature, specifically, a 55% capability at -110°F (194°K), 65% at -320°F (78°K), 60% at -423°F (20°K), compared to a 50% capability at room temperature. However, the additional uniform strain capability of this material at the cryogenic temperatures proved to be of no tangible value. It was strained the greatest amount at -320°F (78°K), 51.5%. After this cryostraining treatment, plus aging, the material had an ultimate tensile strength of 206 400 psi (142 300 N/cm^2), a tensile yield strength of 188 300 psi (129 830 N/cm^2), and an elongation of 3.0%. But, material that was strained 39.5% at room temperature and then aged had an ultimate tensile strength of 200 700 psi (138 400 N/cm^2), a tensile yield strength of 180 600 psi (124 500 N/cm^2) and an elongation of 2.5%. Thus, the additional 12% strain at -320°F (78°K) resulted in only a 2.8% increase in the ultimate tensile strength, and a 4.3% increase in the tensile yield strength of the material. Consequently, cryostraining is not a practical method for strengthening this beryllium copper alloy.

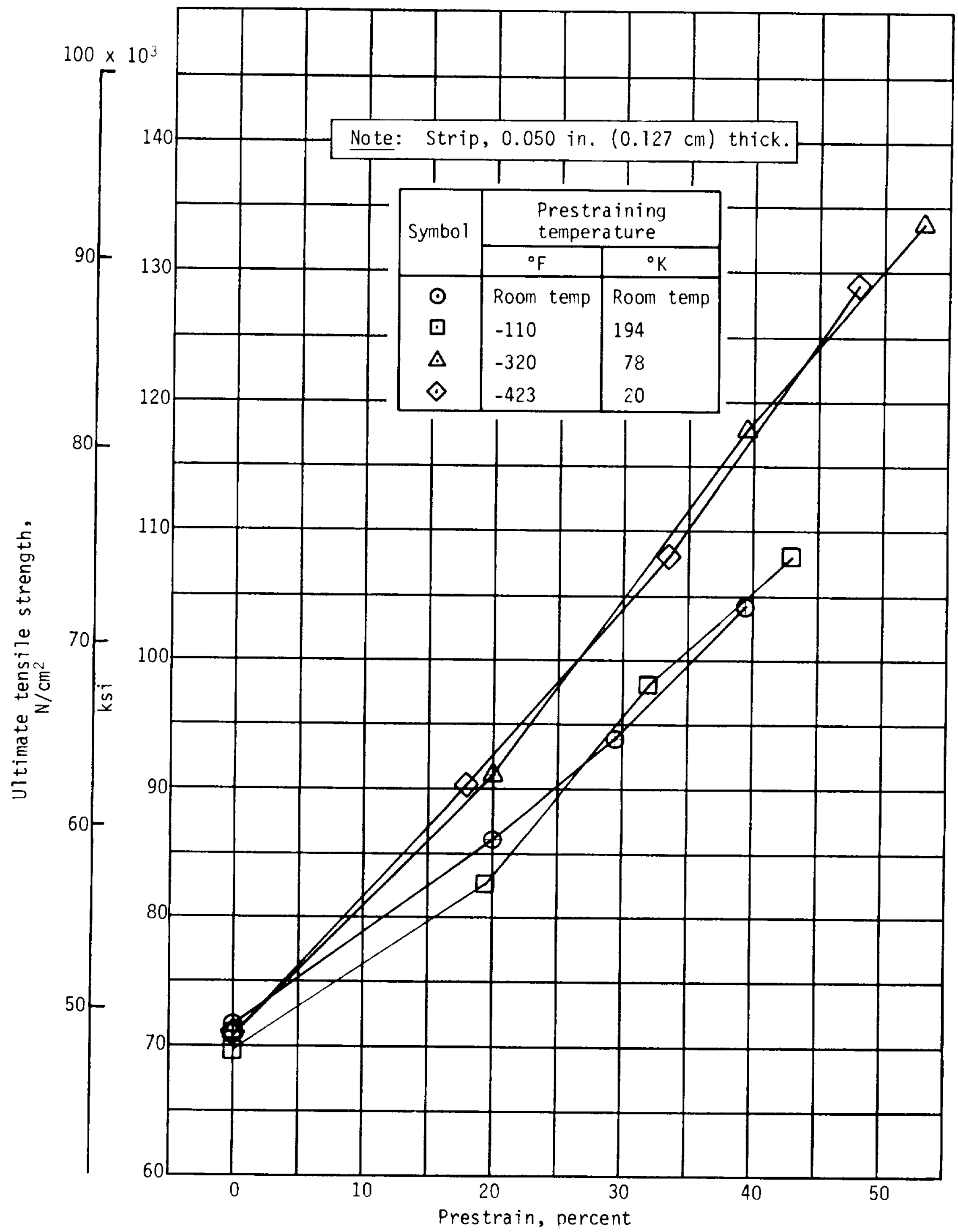


Figure 27.- Ultimate Tensile Strength of Prestrained Beryllium Copper

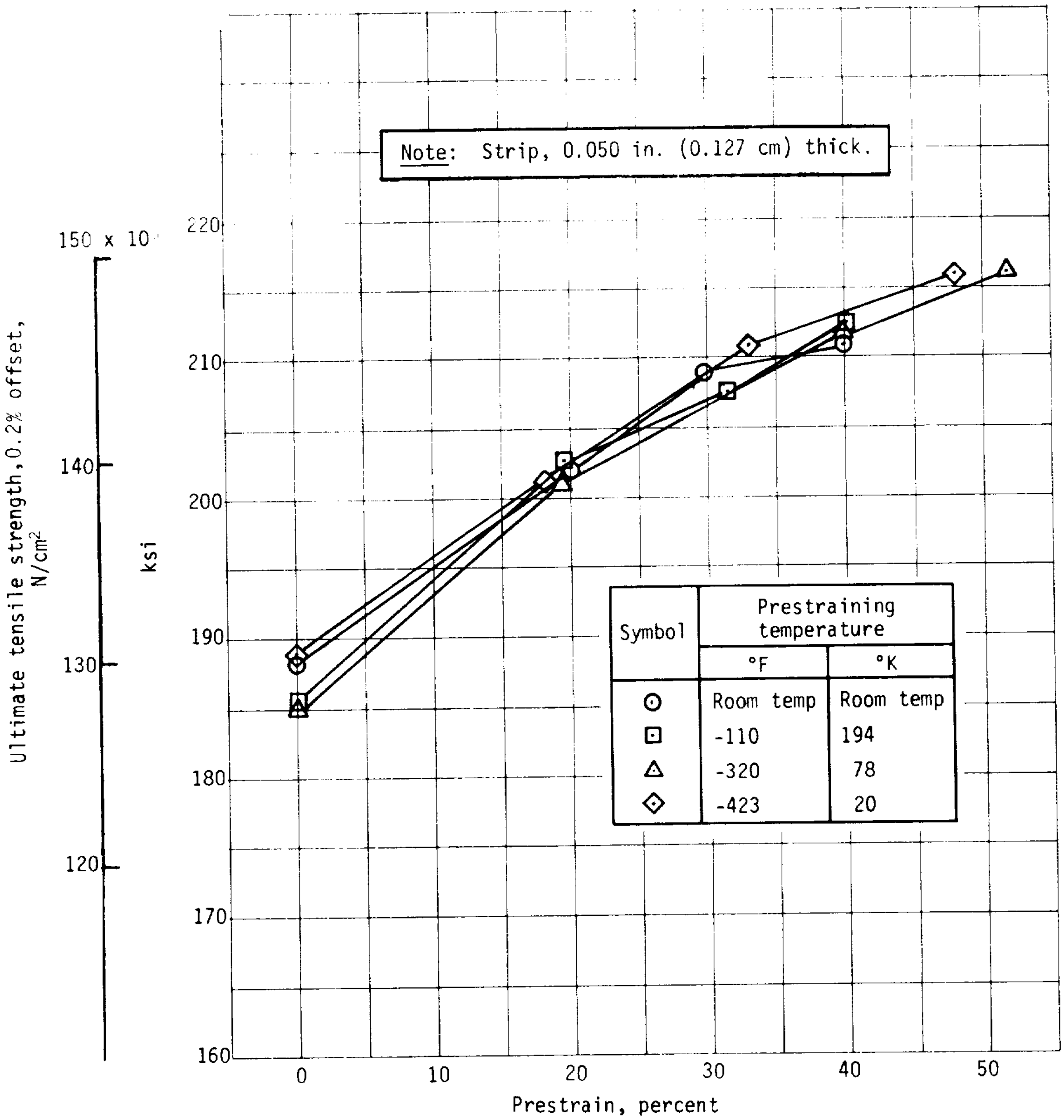


Figure 28.- Ultimate Tensile Strength of Prestrained Beryllium Copper Aged 3 hr at 600°F (589°K)

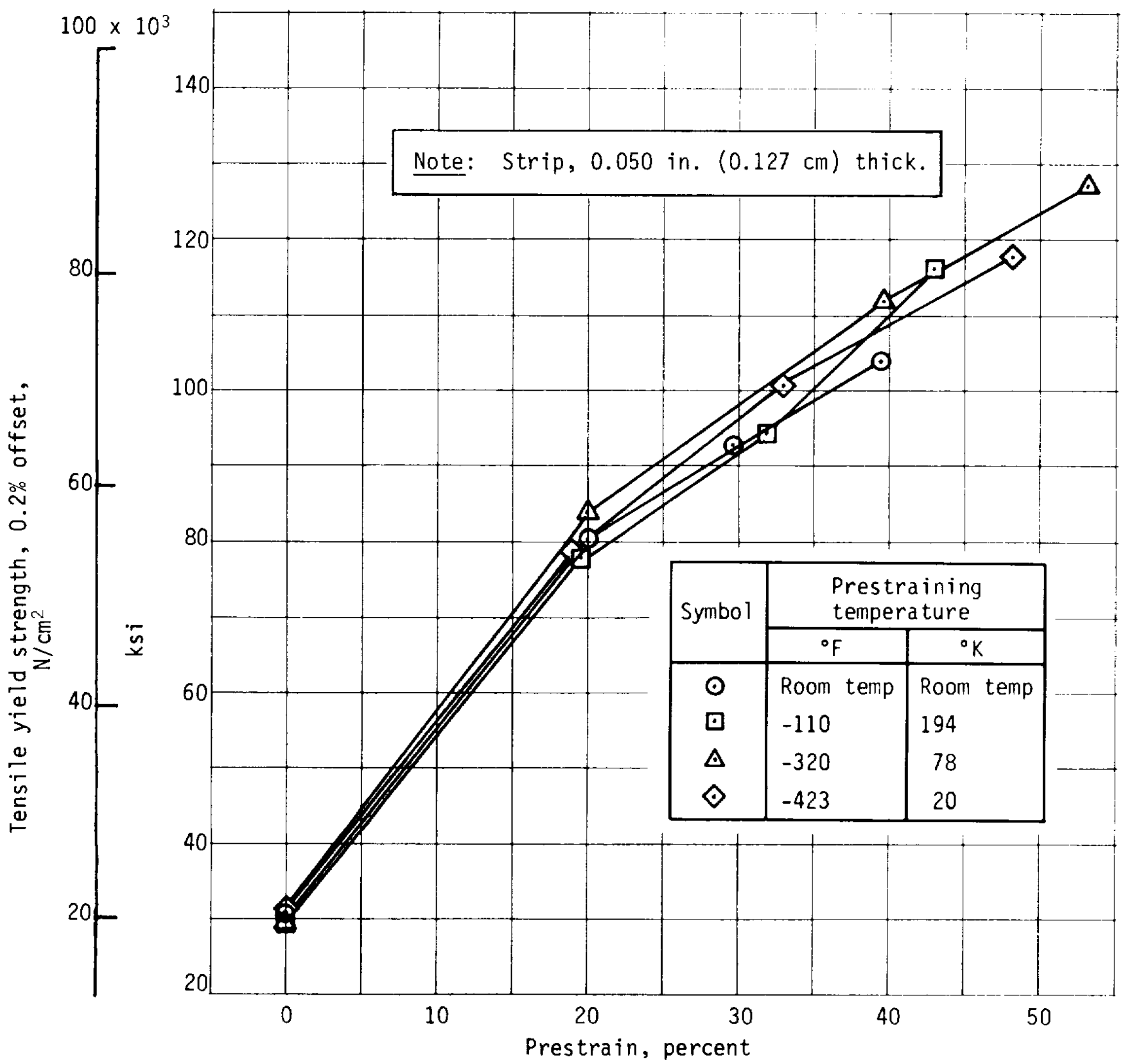


Figure 29.- Tensile Yield Strength of Prestrained Beryllium Copper

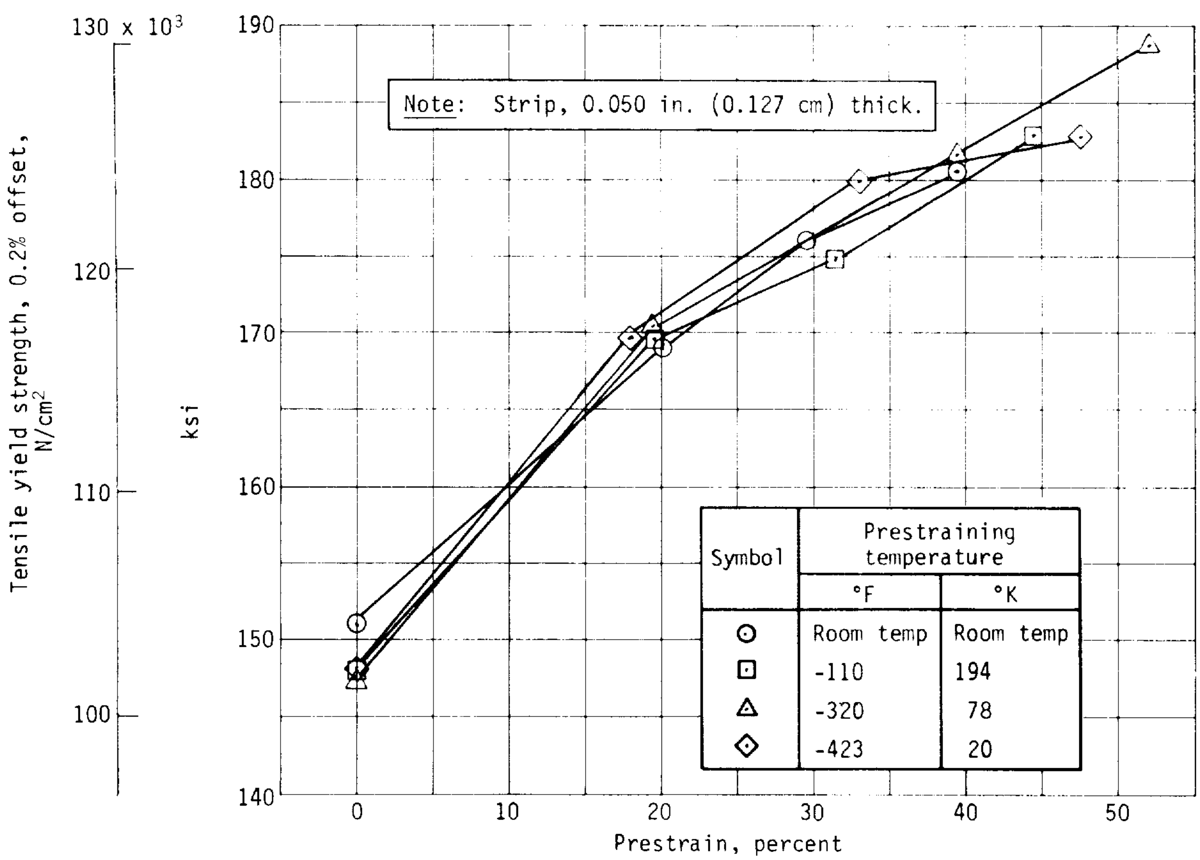


Figure 30.- Tensile Yield Strength of Prestrained Beryllium Copper Aged 3 hr at 600°F (589°K)

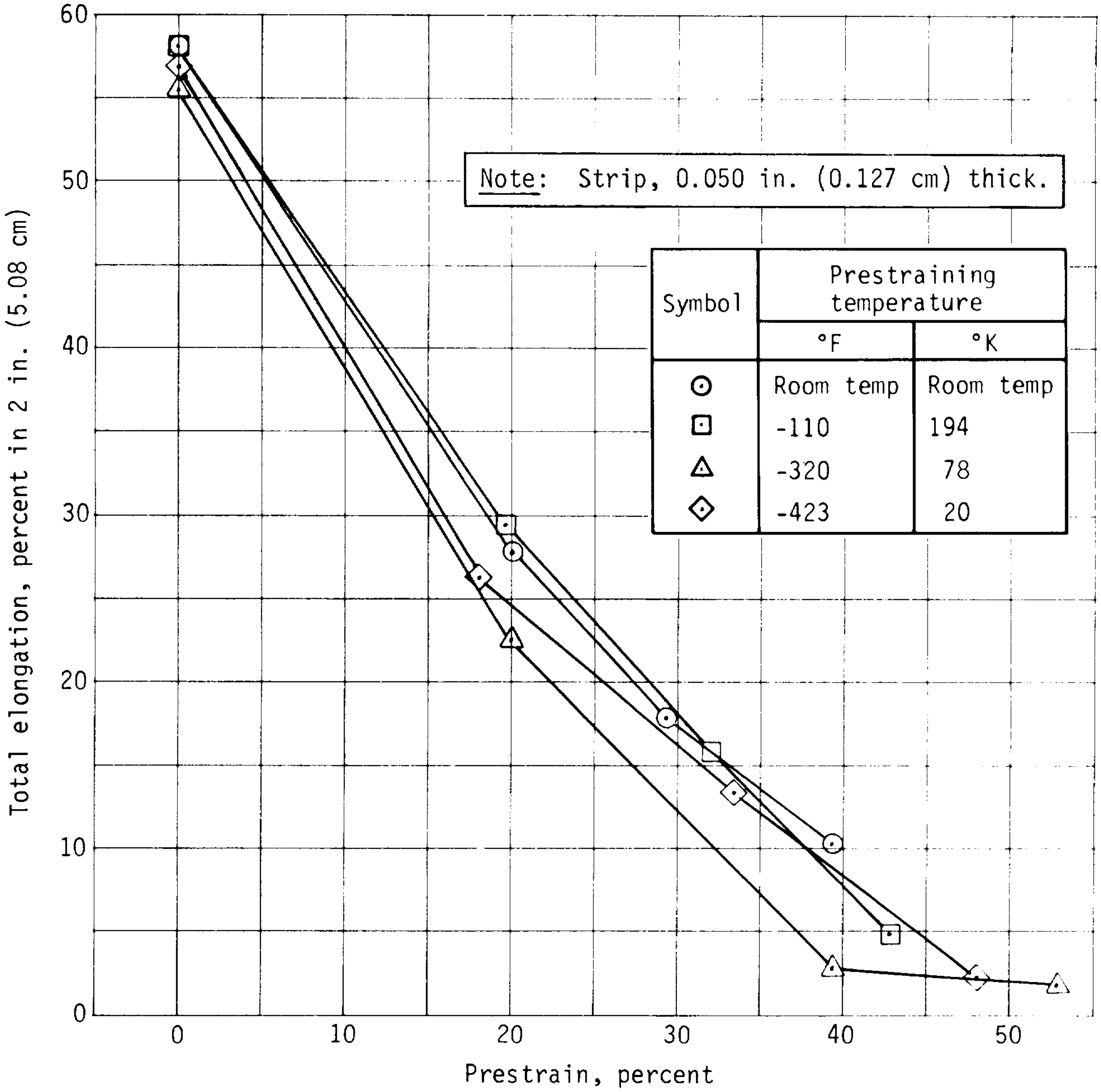


Figure 31.- Total Elongation of Prestrained Beryllium Copper

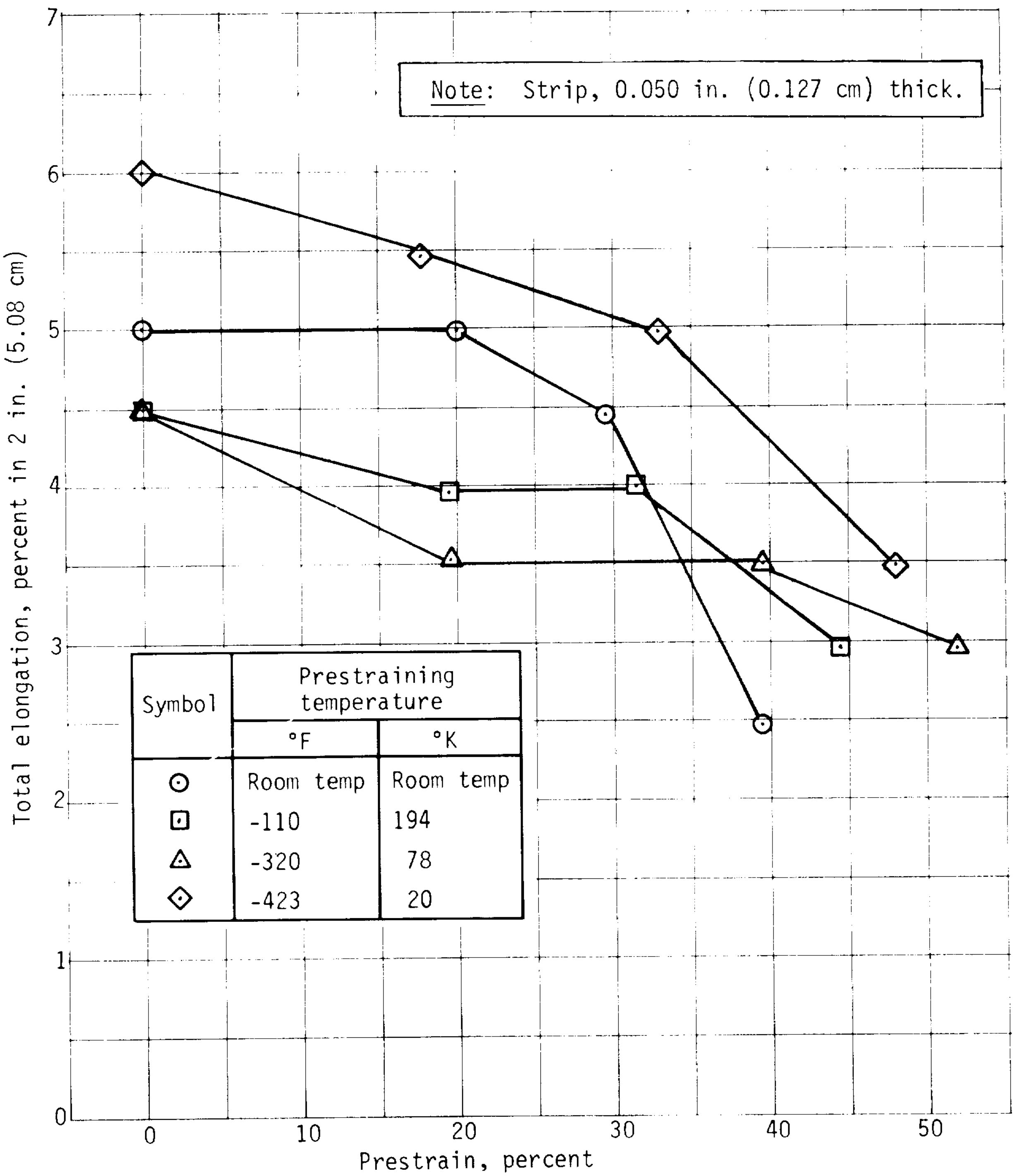
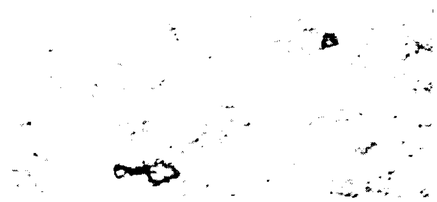
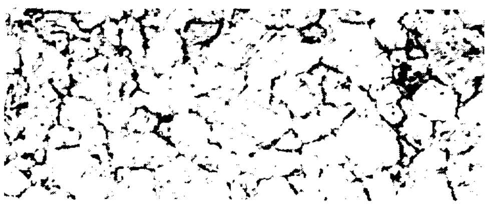


Figure 32.- Total Elongation of Prestrained Beryllium Copper, Aged 3 hr at 600°F (589°K)

(a) 39.5% Strain at Room Temperature, Unaged

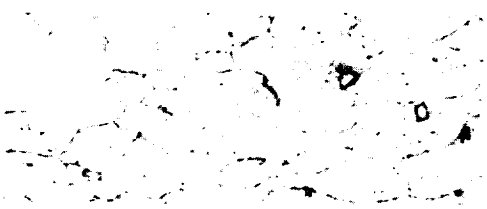


(b) Soaked at -110°F (194°K), Unaged



(c) Soaked at -110°F (194°K), Aged 3 hr at 600°F (589°K)

(d) 43.0% Strain at -110°F, Unaged



(e) 44.5% Strain at -110°F (194°K), Aged 3 hr at 600°F (589°K)

(f) Soaked at -320°F (78°K), Unaged

Note: The strained and unaged structures are characterized by indistinct grain boundaries and a high amount of twinning. The aged structures show less evidence of straining and more distinct grain boundaries.

Electroetch: CrO_3 500X

Figure 33.- Microstructure of Beryllium Copper Alloy

L-605 Cobalt Alloy

A sheet of annealed L-605, 0.068x36x96 in. (0.173x92x244 cm) was procured to material specification AMS-5537C. The chemical composition of this sheet was:

Element	Percent by weight
C	0.118
S	0.011
Mn	1.70
Si	0.21
Cr	19.90
Fe	1.55
Ni	10.00
P	0.009
W	14.9
Co	Balance

Density: 0.330 lb/cu in.; 9.13 gm/cc

The L-605 specimens were prepared and processed in the manner described in Chapter III, with one exception. After straining the specimens were remachined to reduce the width and thus the area of the highly strained gage section to prevent out-of-gage failures during subsequent tensile tests.

The L-605 specimens that required aging were aged 4 hr at 1100°F (866°K) and air cooled. These specimens were thoroughly cleaned and coated with a protective lacquer before they were aged.

The results of the tests conducted on the L-605 specimens are given in figures 34 through 39, and are listed in tables 10 and 11 of the Appendix. Figure 40 shows photomicrographs of the microstructure of L-605 in various conditions.

The uniform strain capability of L-605 decreases as temperature decreases. Also, a given amount of strain produces about the same strengthening effect regardless of whether the material is strained at room temperature or at a cryogenic temperature. Consequently, there is no advantage to be gained from cryostraining L-605.

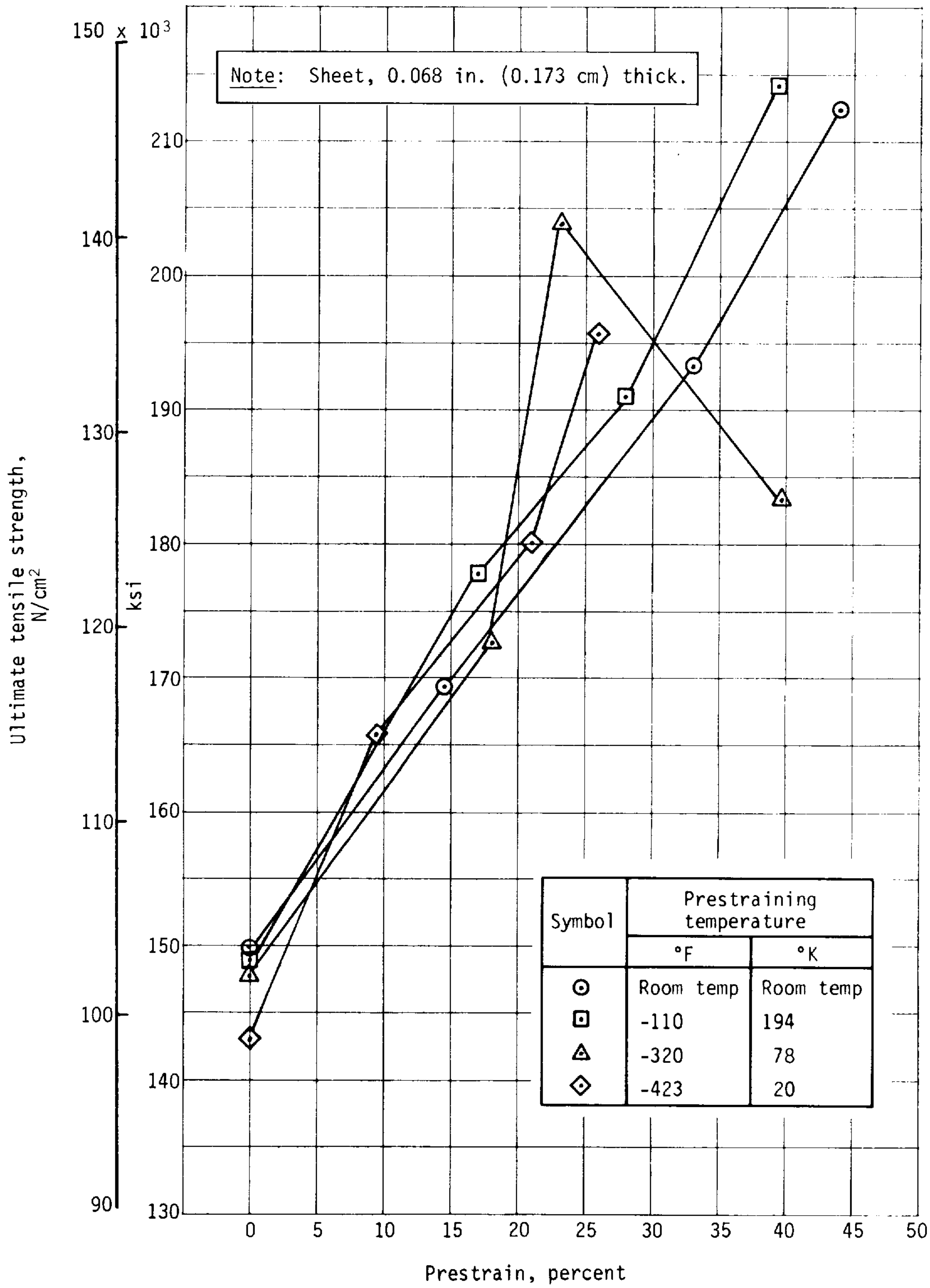


Figure 34.- Ultimate Tensile Strength of Prestrained L-605 Cobalt Alloy

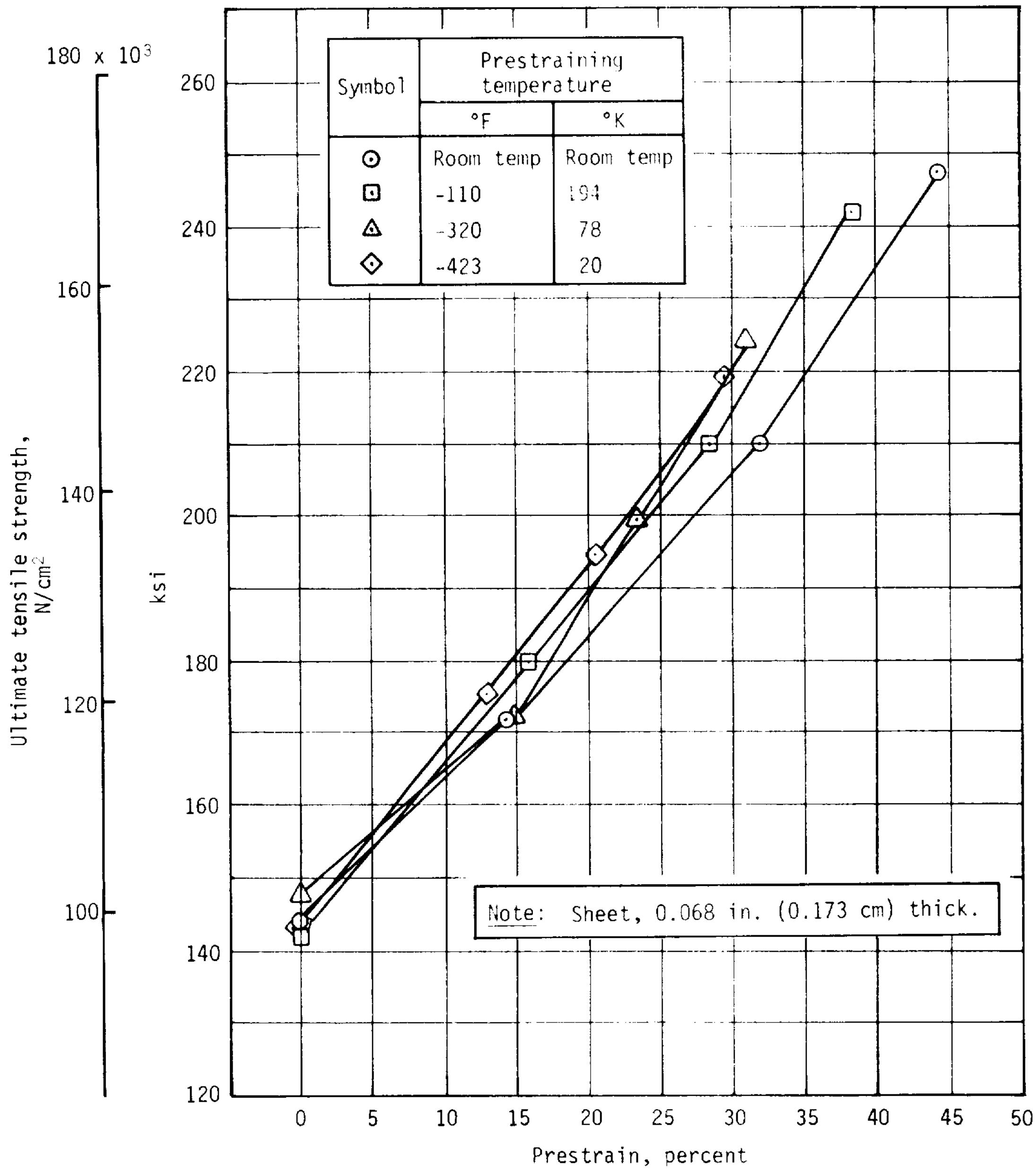


Figure 35.- Ultimate Tensile Strength of Prestrained L-605 Aged 4 hr at 1100°F (866°K)

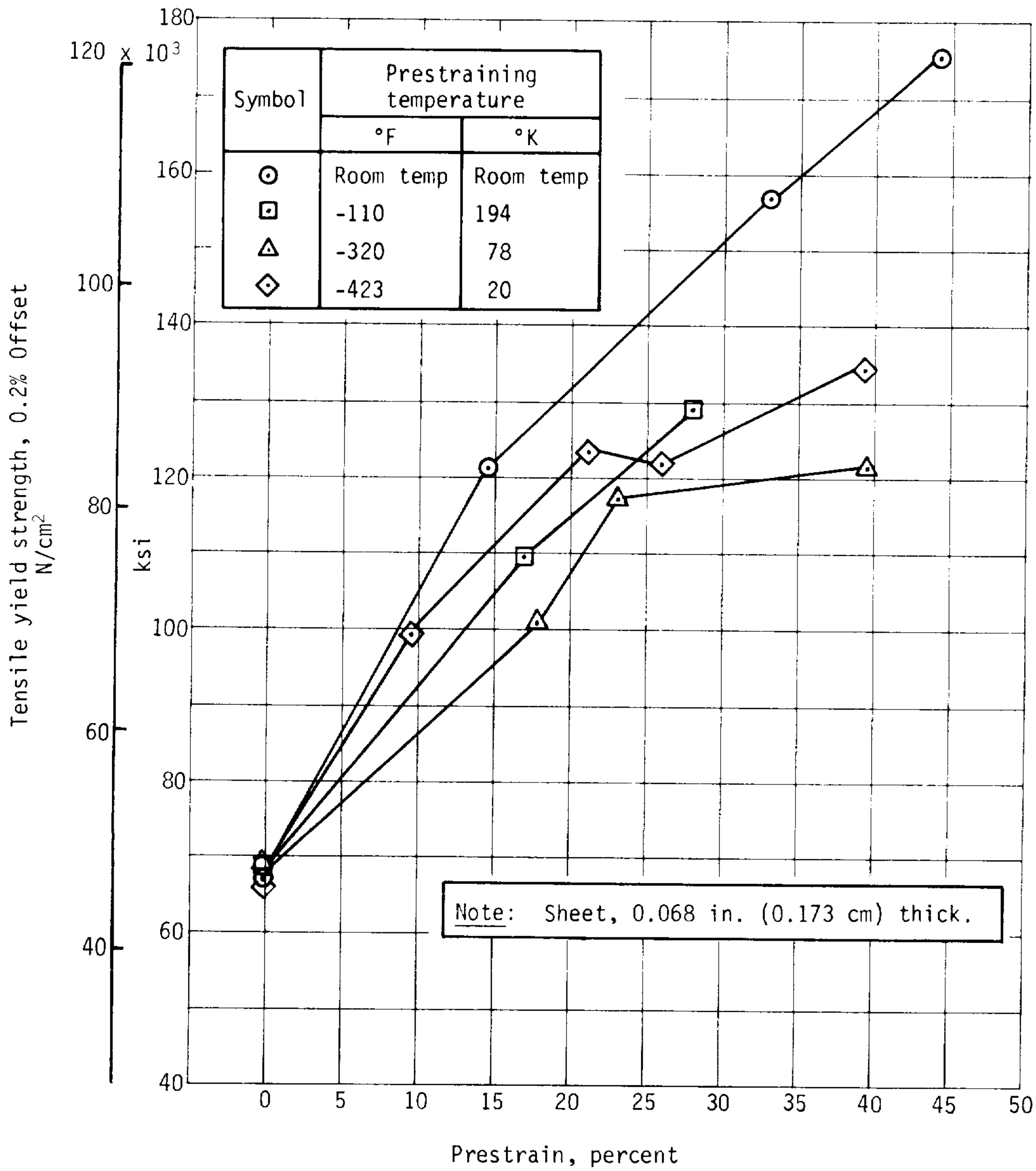


Figure 36.- Tensile Yield Strength of Prestrained L-605 Cobalt Alloy

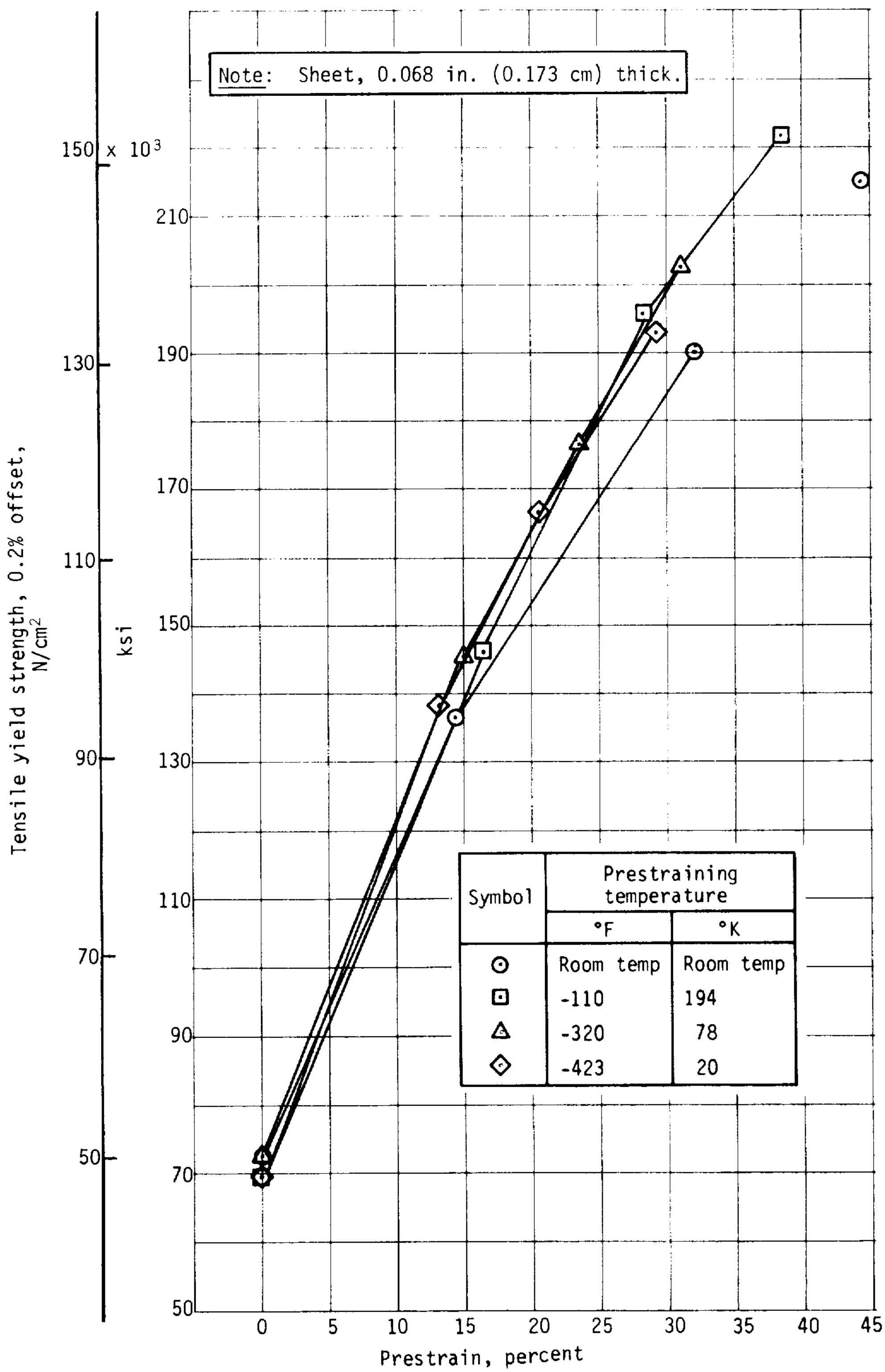


Figure 37.- Tensile Yield Strength of Prestrained L-605, Aged 4 hr at 1100°F (866°K)

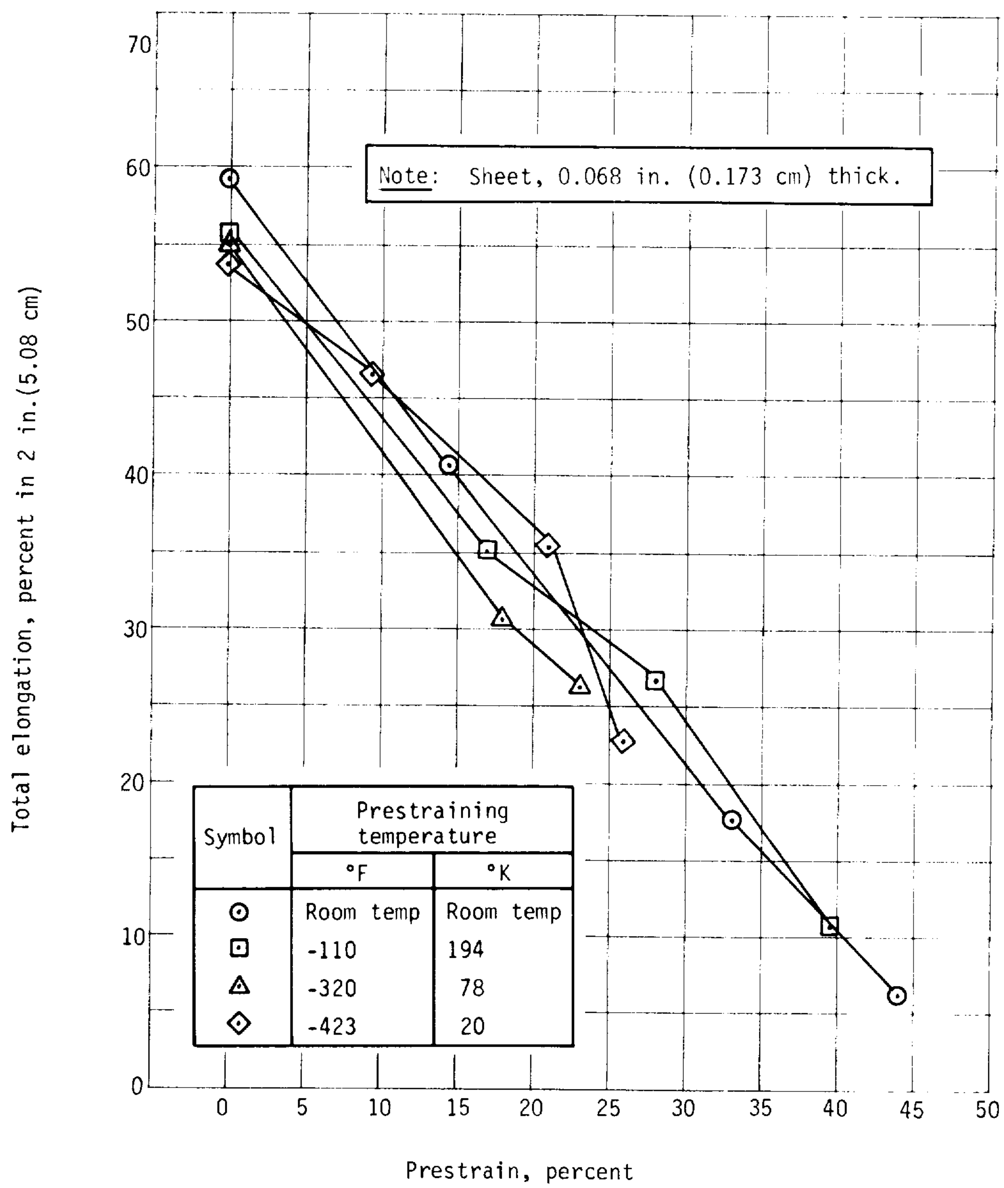


Figure 38.- Total Elongation of Prestrained L-605 Cobalt Alloy

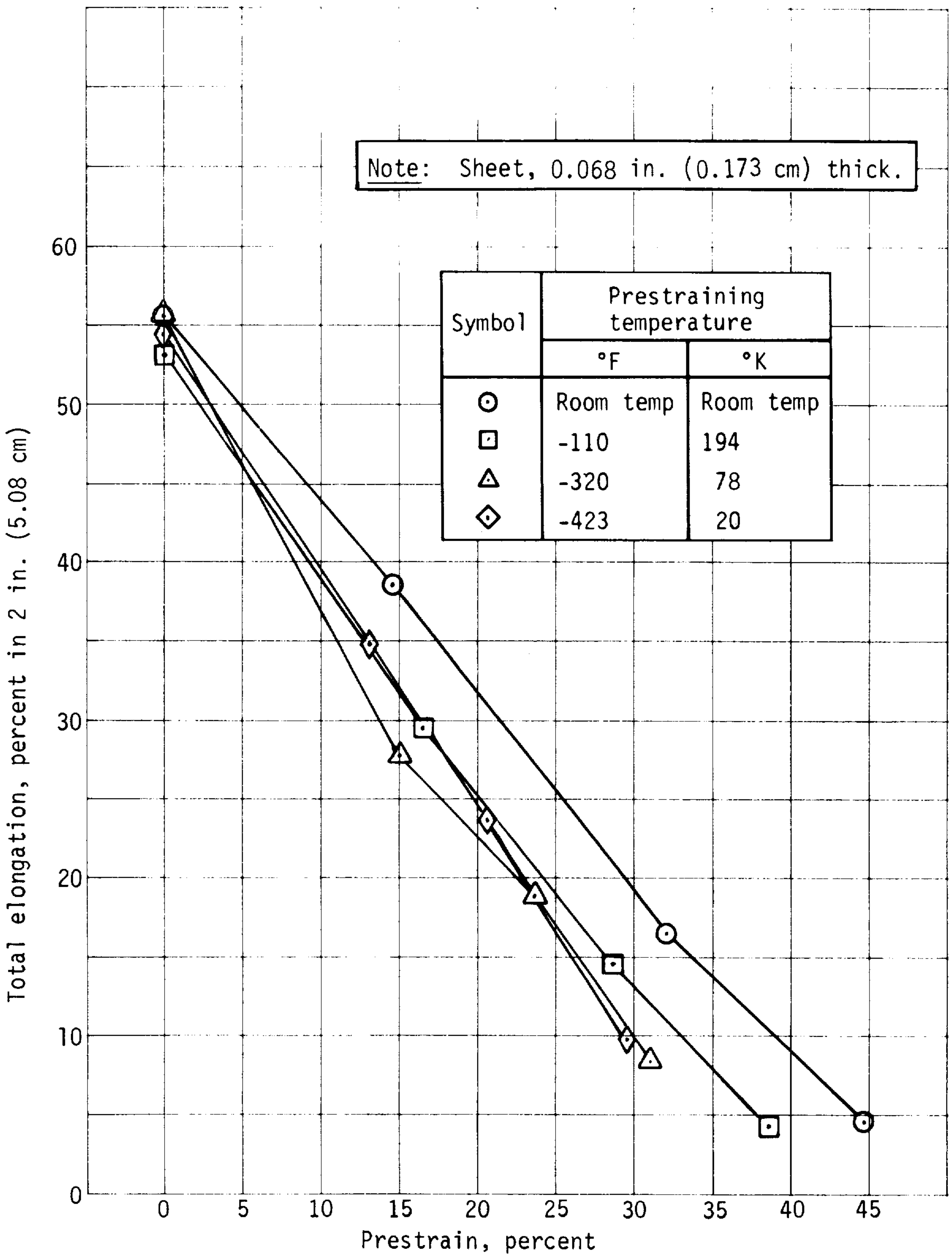
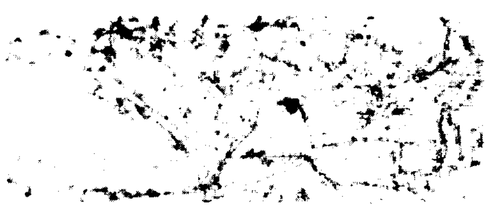


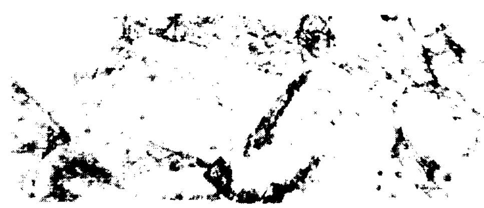
Figure 39.- Total Elongation of Prestrained L-605. Aged 4 hr at 1100°F (866°K)

(a) Soaked at Room Temperature, Unaged

(b) Soaked at Room Temperature, Aged 4 hr at 1100°F (866°K)



(c) 31.0% Strain at -320°F (78°K), Aged 4 hr at 1100°F (866°K)



(d) 29.5% Strain at -423°F (20°K), Aged 4 hr at 1100°F (866°K)

Note:	Aging does not produce any distinguishable changes to the microstructure. Straining produces significant evidence in the form of twinning.

Electroetch: Oxalic acid 250X

Figure 40.- Microstructure of L-605 Cobalt Alloy

MP 35 N Cobalt-Nickel Multiphase Alloy

A sheet of annealed MP 35 N, 0.060x30x48 in. (0.152x76x122 cm) was procured to commercial requirements. The chemical composition of this sheet was:

Element	Percent by weight
Ni	33.5
Co	38.9
Cr	18.6
Mo	7.2

Density: 0.304 lb/cu in.; 8.41 gm/cc

Because of the comparatively small size of the MP 35 N sheet available for the program it was necessary to strain less than the normal amount of specimens at each temperature. Normally, for a heat-treatable alloy, 40 specimens were conditioned at each temperature, for MP 35 N, only 30 specimens were conditioned at each of the four temperatures.

Another deviation from normal processing was that the specimens were remachined after they were strained to reduce the width, and thus the area, of the highly strained gage sections to prevent out-of-gage failures during subsequent tensile tests.

The MP 35 N specimens that required aging were aged 4 hr at 900°F (756°K) and air cooled. These specimens were thoroughly cleaned and coated with a protective lacquer before they were aged.

The results of the tests conducted on the MP 35 N specimens are given in figures 41 through 46, and are listed in tables 12 and 13 of the Appendix. Figure 47 shows photomicrographs of the microstructure of MP 35 N in various conditions.

MP 35 N has a higher uniform strain capability at cryogenic temperatures than at room temperature, specifically, 55% at room temperature, 70% at -110°F (194°K), 70% at -320°F (78°K) and 75% at -423°F (20°K). Also, a given amount of strain will result in higher strengths as the temperature at which the material is strained is lowered. For example, when strained 22% at room temperature and aged the MP 35N sheet had an ultimate tensile strength of 155 000 psi (107 000 N/cm^2), a tensile yield strength of 128 900 psi (88 800 N/cm^2), and an elongation of 32.0%. After being strained 22.5% at -320°F (78°K) the MP 35 N sheet had an ultimate tensile strength of 163 400 psi (112 700 N/cm^2), a tensile yield strength of 147 000 psi (101 400 N/cm^2), and an elogation of 27.5%. Straining at cryogenic temperatures is a method by which MP 35 N can be strengthened. Also, since this alloy can be strained greater amounts at the cryogenic temperatures than at room temperature, much higher strength can be developed through cryostraining than by straining at room temperature.

However, when MP 35 N was strained at any of the four temperatures to approximately 80% of its uniform strain capability at the temperature, its elongation was reduced to 2 to 3% (except 8.5% at room temperature), and its tensile yield strength equaled or almost equaled its ultimate strength. Consequently, the toughness of the material after it has been highly strained at any temperature is questionable.

The program covered by this report was conducted to determine whether or not the alloys investigated during the course of the program could be strengthened more by straining them at cryogenic temperatures than by straining them at room temperature. MP 35 N is a multiphase cobalt-nickel alloy that is strengthened by strain hardening and aging. Strain induces a local shear transformation in which platelets of a hexagonal close packed structure form within the face centered cubic matrix. The amount of transformation product formed is dependent upon the amount of strain deformation. The results of the tests conducted on the MP 35 N sheet show that MP 35 N develops higher strength for a given amount of strain when it is strained at cryogenic temperatures compared to room temperature straining. From this it can be hypothesized that the strain-induced transformation, by which this alloy is strengthened, is enhanced when the alloy is strained at cryogenic temperatures, and that cryostraining increases the alloy's response to aging. The combination of these effects, as shown by the test results, make cryostraining a method by which MP 35 N can be significantly strengthened. Further characterization studies of MP 35 N should be conducted when the material is more readily available in sheet form.

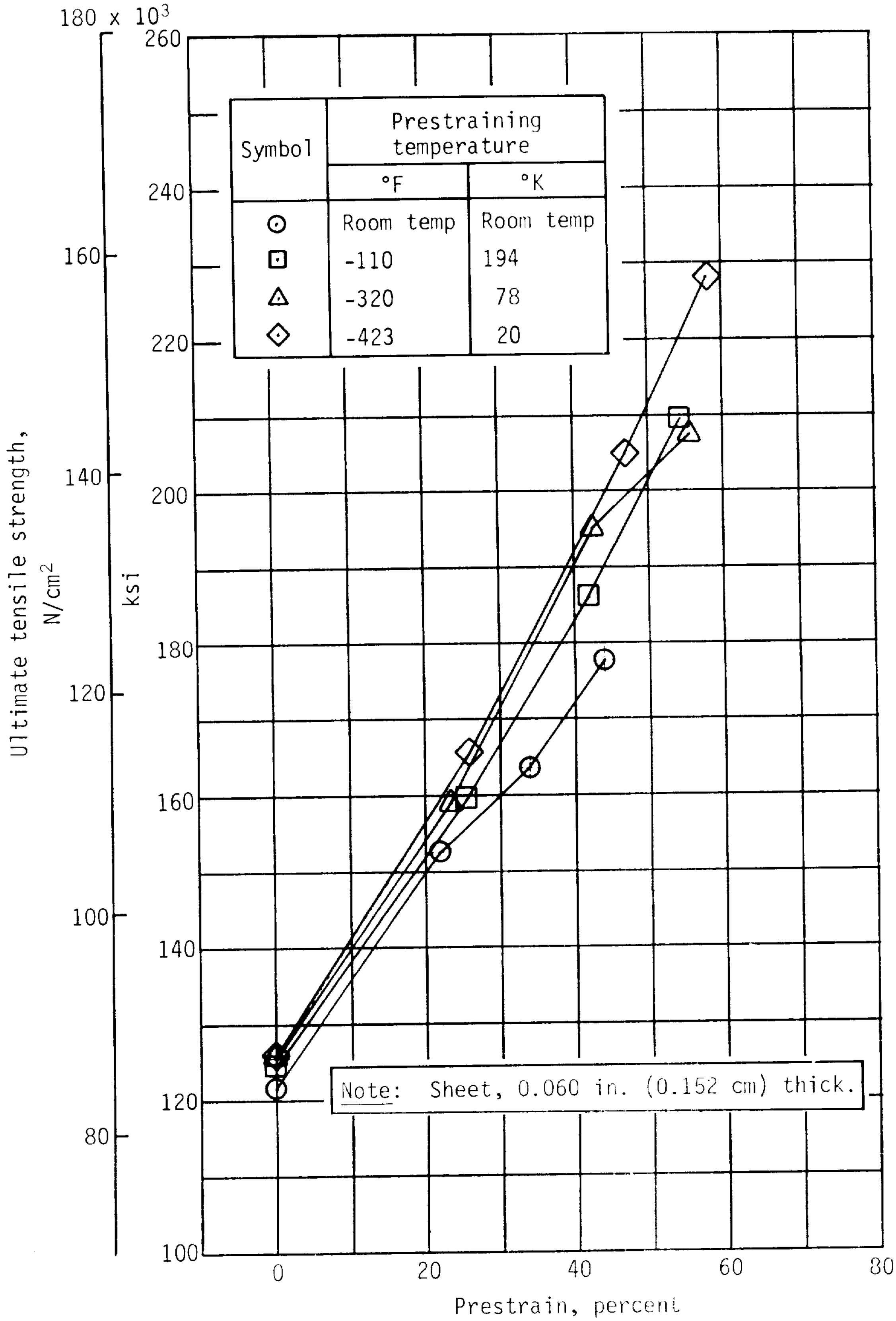


Figure 41.- Ultimate Tensile Strength of Prestrained MP 35 N Cobalt-Nickel Alloy

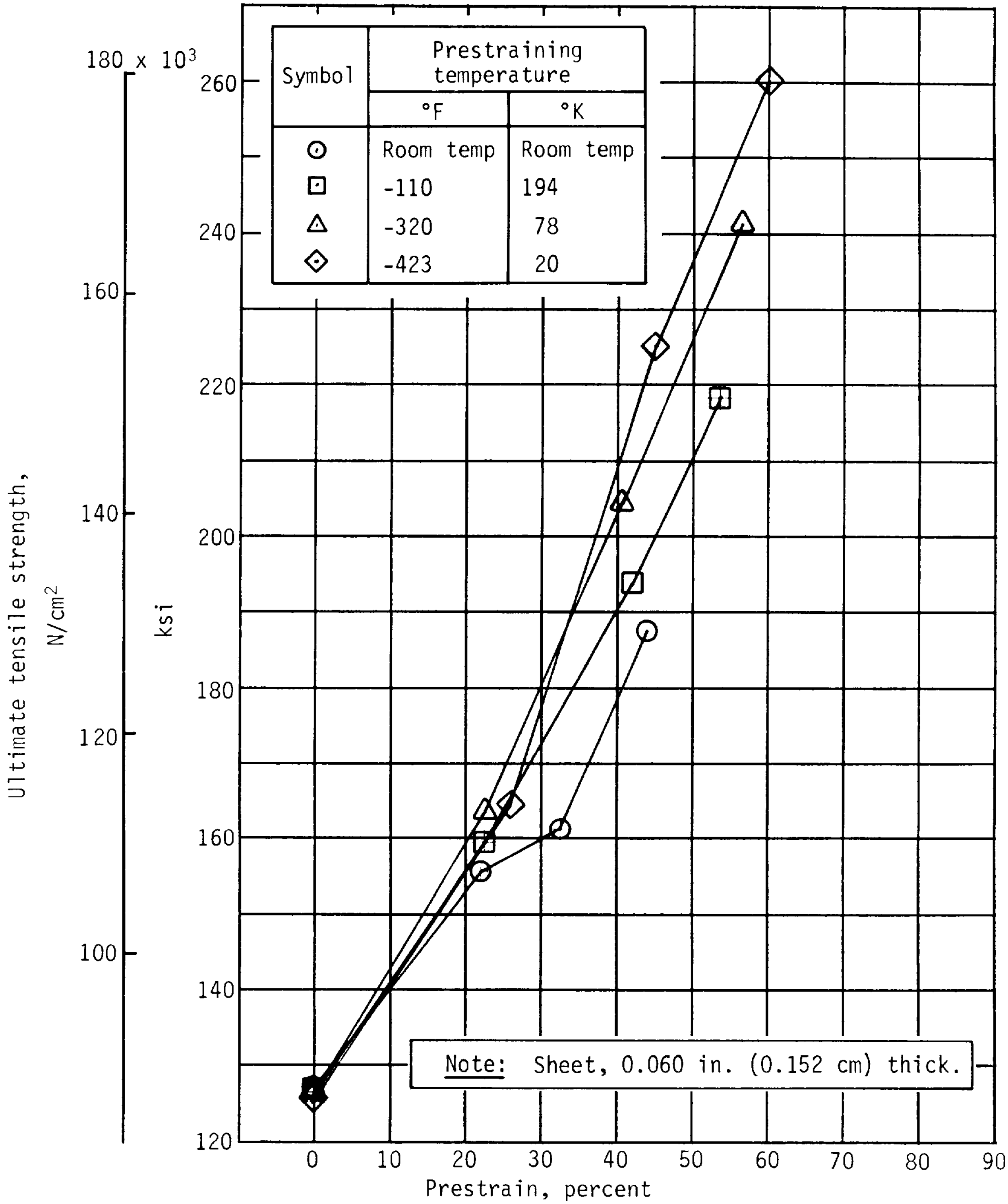


Figure 42.- Ultimate Tensile Strength of Prestrained MP 35 N Cobalt-Nickel Alloy, Aged 4 hr at 900°F (756°K)

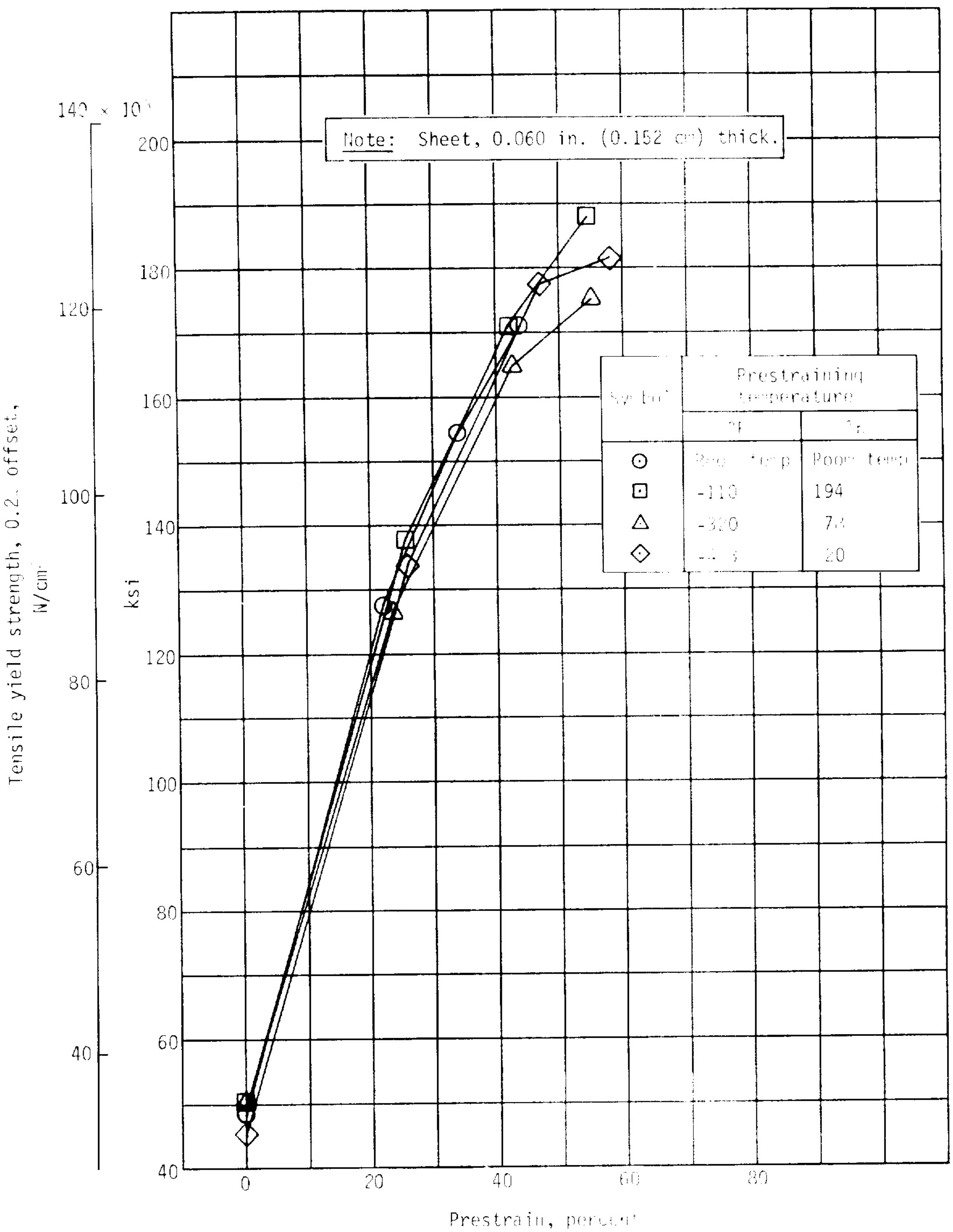


Figure 43.- Tensile Yield Strength of Prestrained MP 35 N Cobalt-Nickel Alloy

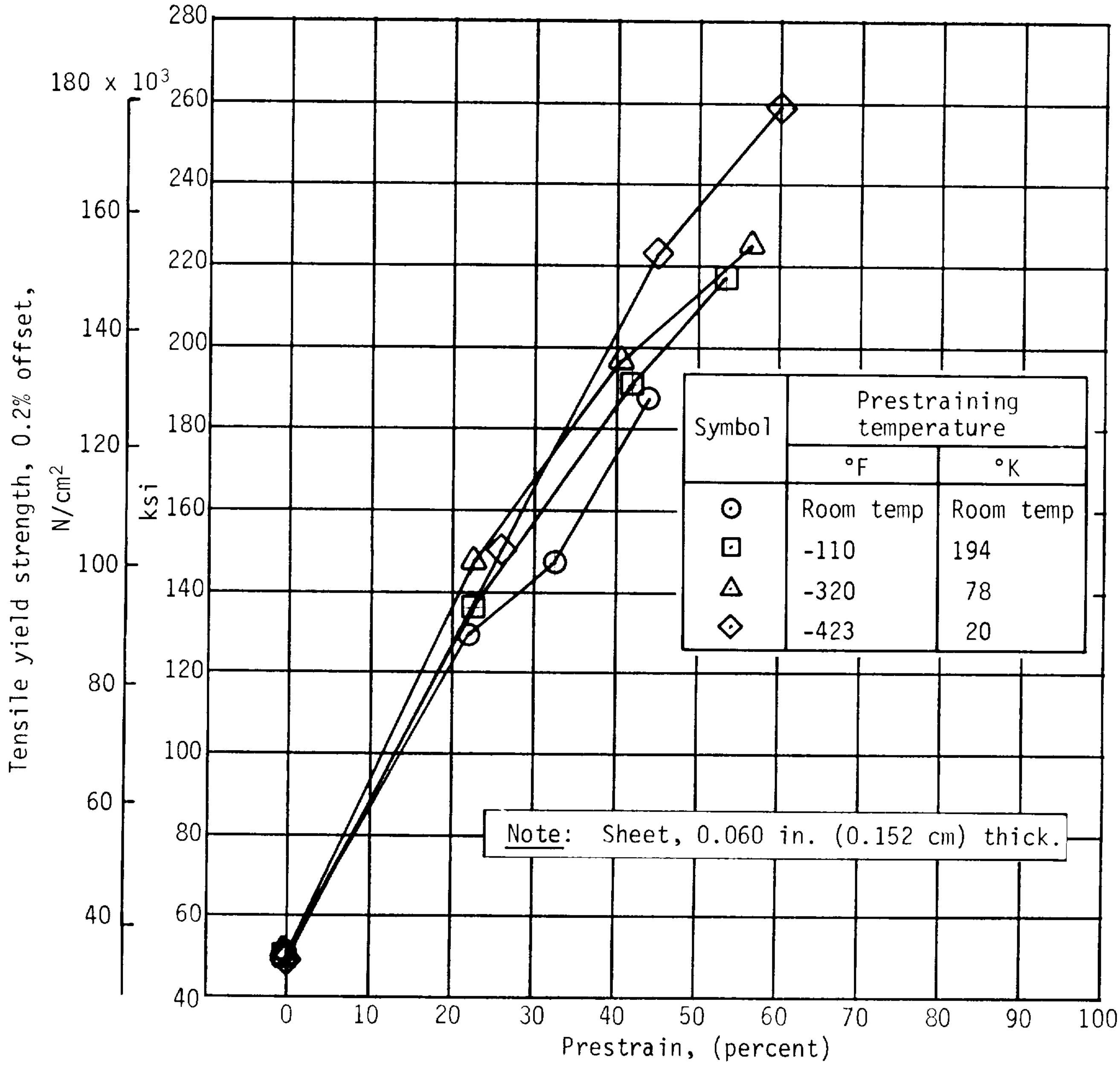


Figure 44.- Tensile Yield Strength of Prestrained MP 35 N Cobalt-Nickel Alloy, Aged 4 hr at 900°F (756°K)

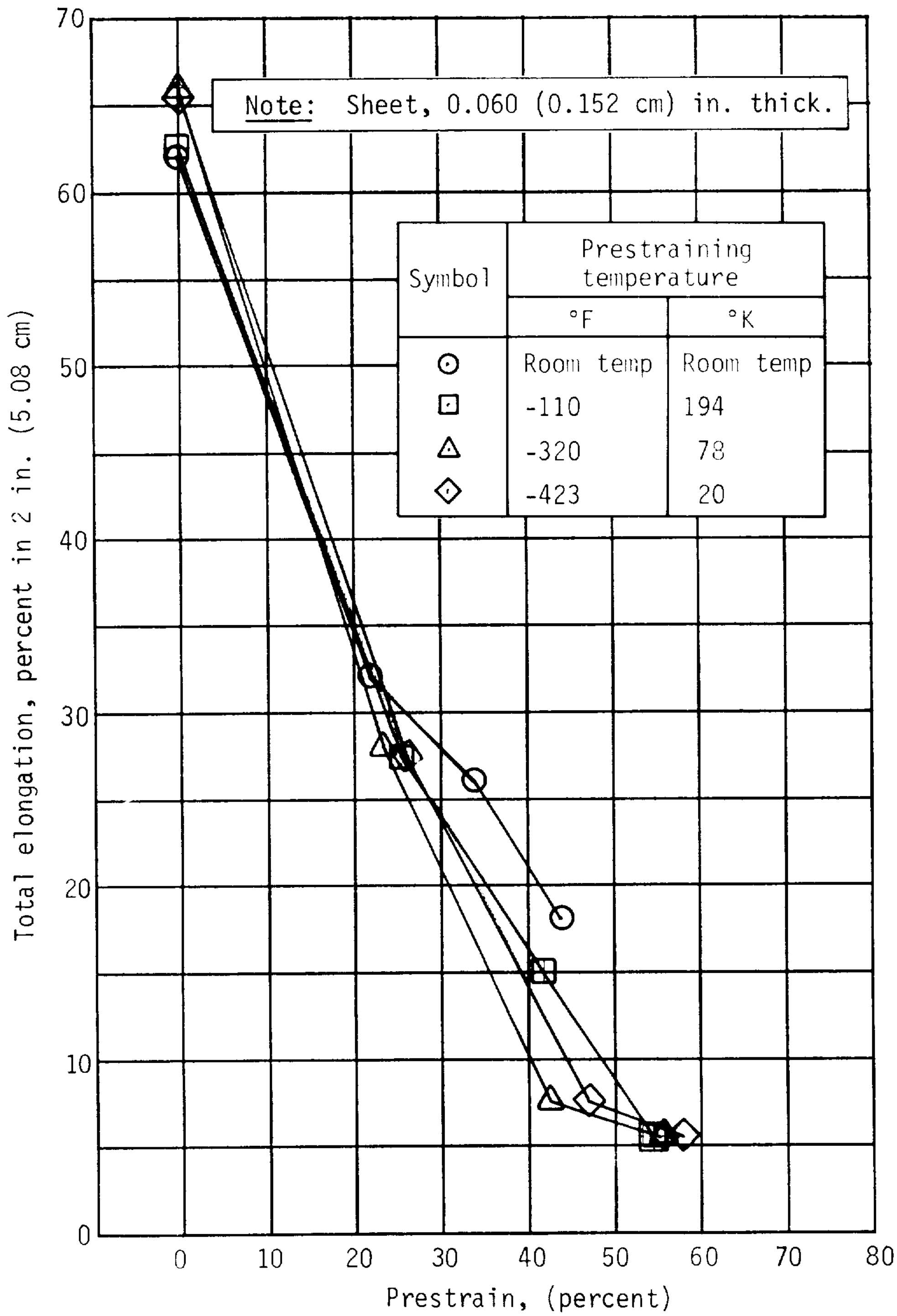


Figure 45.- Total Elongation of Prestrained MP 35 N Cobalt-Nickel Alloy

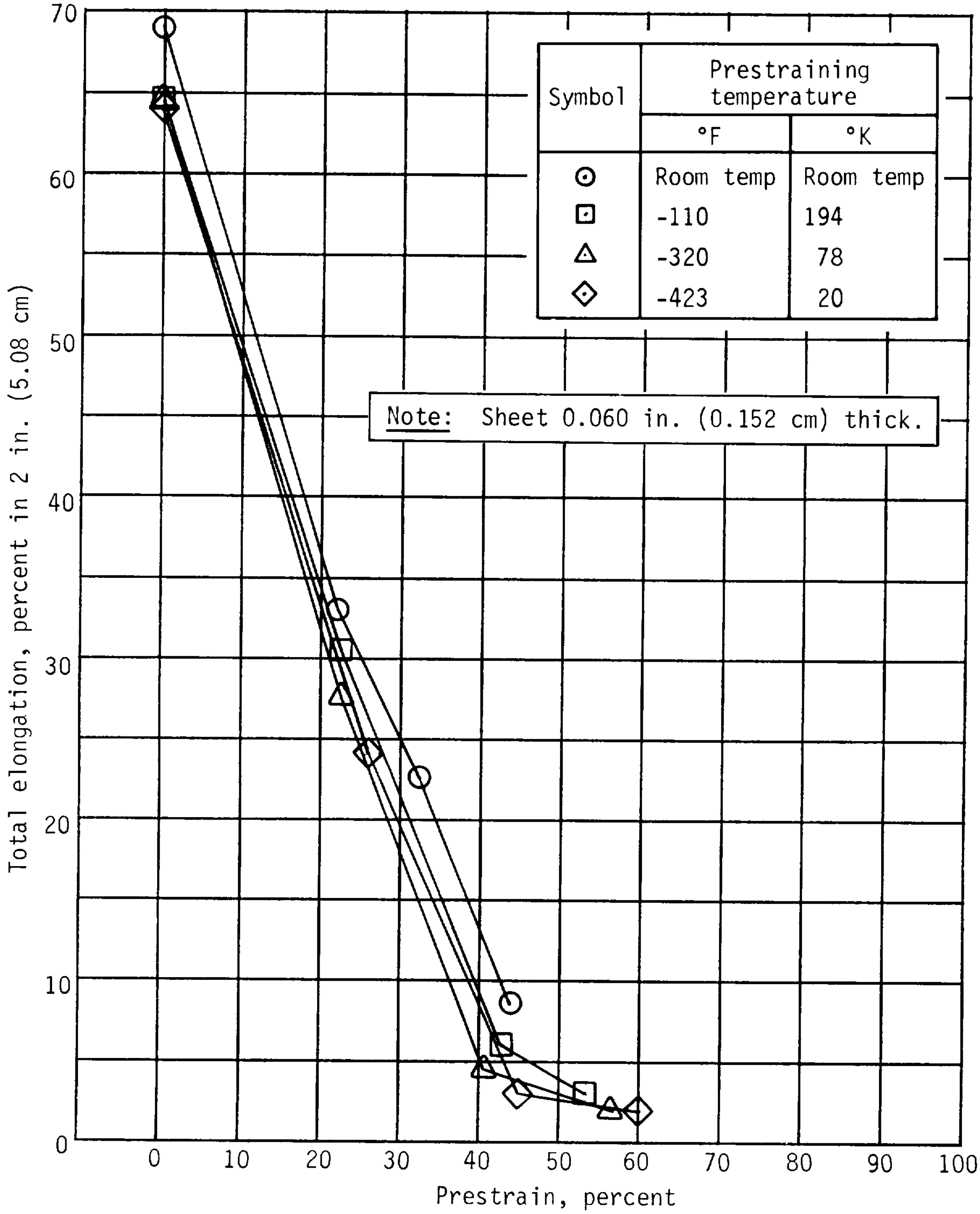
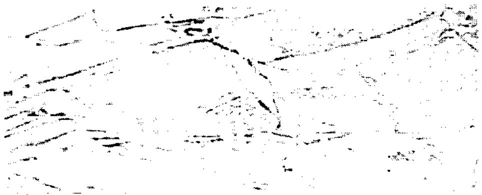
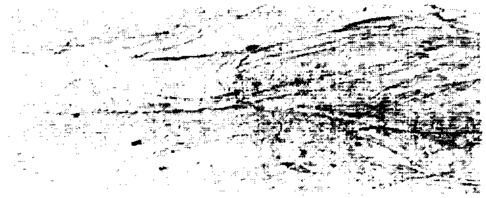


Figure 46.- Total Elongation of Prestrained MP 35 N Cobalt-Nickel Alloy, Aged 4 hr at 900°F (756°K)



(a) Soaked at Room Temperature, Unaged



(b) Soaked at Room Temperature, Aged 4 hr at 900°F (756°K)

(c) 44.0% Strain at Room Temperature, Aged 4 hr at 900°F (756°K)

(d) 53.5% Strain at -110°F (194°K), Aged 4 hr at 900°F (756°K)

(e) 56.5% Strain at -320°F (78°K), Aged 4 hr at 900°F (756°K)

(f) 60.0% Strain at -423°F (20°K), Aged 4 hr at 900°F (756°K)

<u>Note</u>: The appearance of the structure in (a) indicates that the differences in structure evident in (a) through (e) are the result of testing the specimens to failure rather than the effects of straining at the different temperatures.

Electroetched: 10% Oxalic acid 250X

Figure 47.- Microstructure of MP 35 N Cobalt-Nickel Alloy

LA141A Magnesium Alloy

Two pieces of LA141A-T7 magnesium alloy sheet, 0.090x36x48 in. (0.229x92 x122 cm), were procured to material specification AMS 4386. The chemical composition of the sheet stock was:

Element	Percent by weight
Aℓ	1.07
Li	13.70
Na	0.0043
Fe	.002
Mn	.058
Mg	Balance

Density: 0.049 lb/cu in.; 1.36 gr/cc

The LA141A specimens were prepared and processed as described in Chapter III. Since the sheet stock had been procured in the stabilized -T7 condition [aged 6 hr at 350°F (450°K)], aging after straining was not appropriate. However, because specimens had been prepared, a number of poststrain low temperature aging treatments were attempted.

The results of the tests conducted on the as-strained LA141A specimens are given in figures 48 through 50, and are listed in tables 14 and 15 of the Appendix, in which the results of the tests conducted on the heat treated specimens are also listed. Figure 51 shows photomicrographs of the structure of LA141A.

Neither cryostraining nor the postcryostraining aging treatments produced any significant strengthening effects on the LA141A-T7 sheet material.

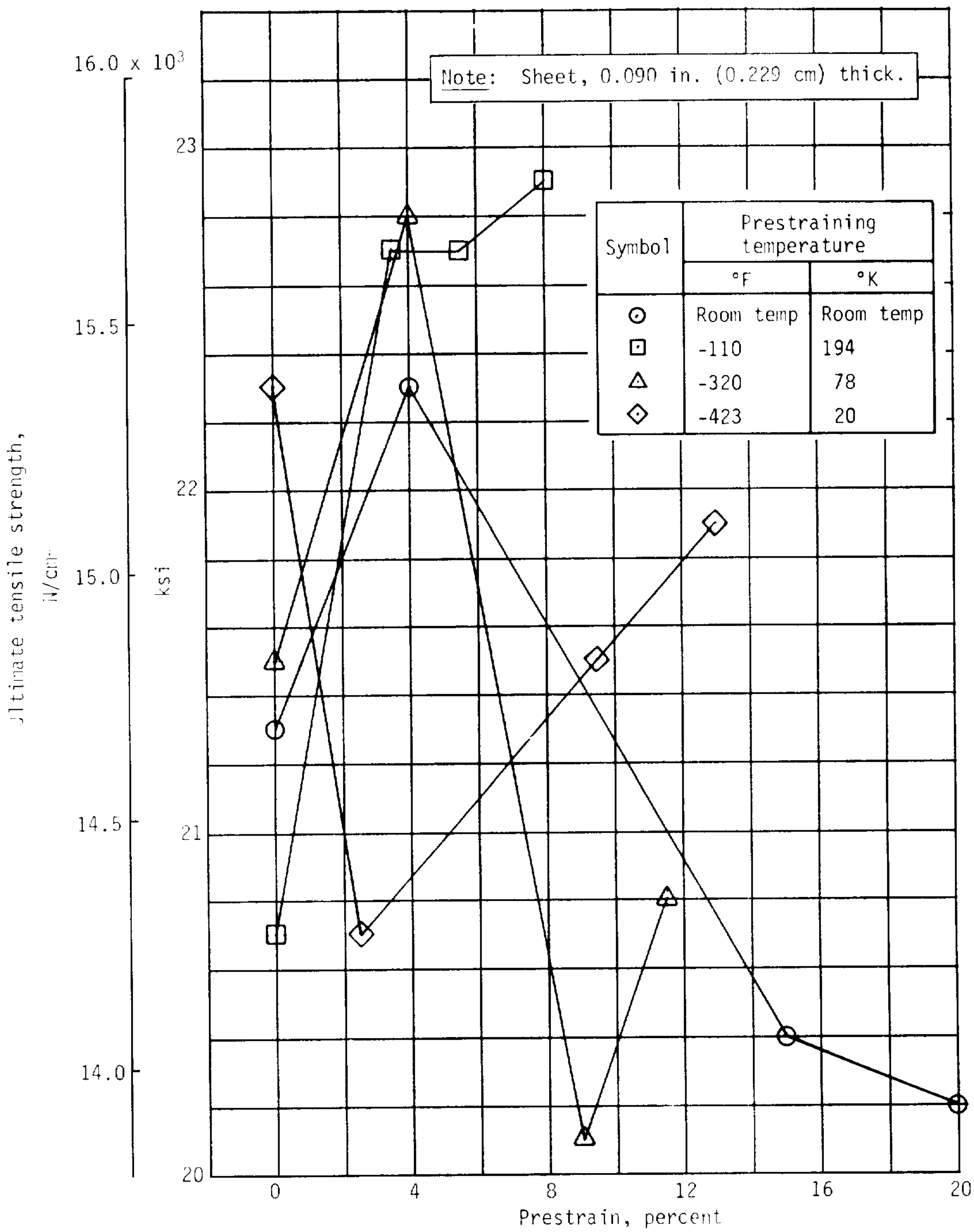


Figure 48.- Ultimate Tensile Strength of Prestrained LA141A Magnesium Alloy

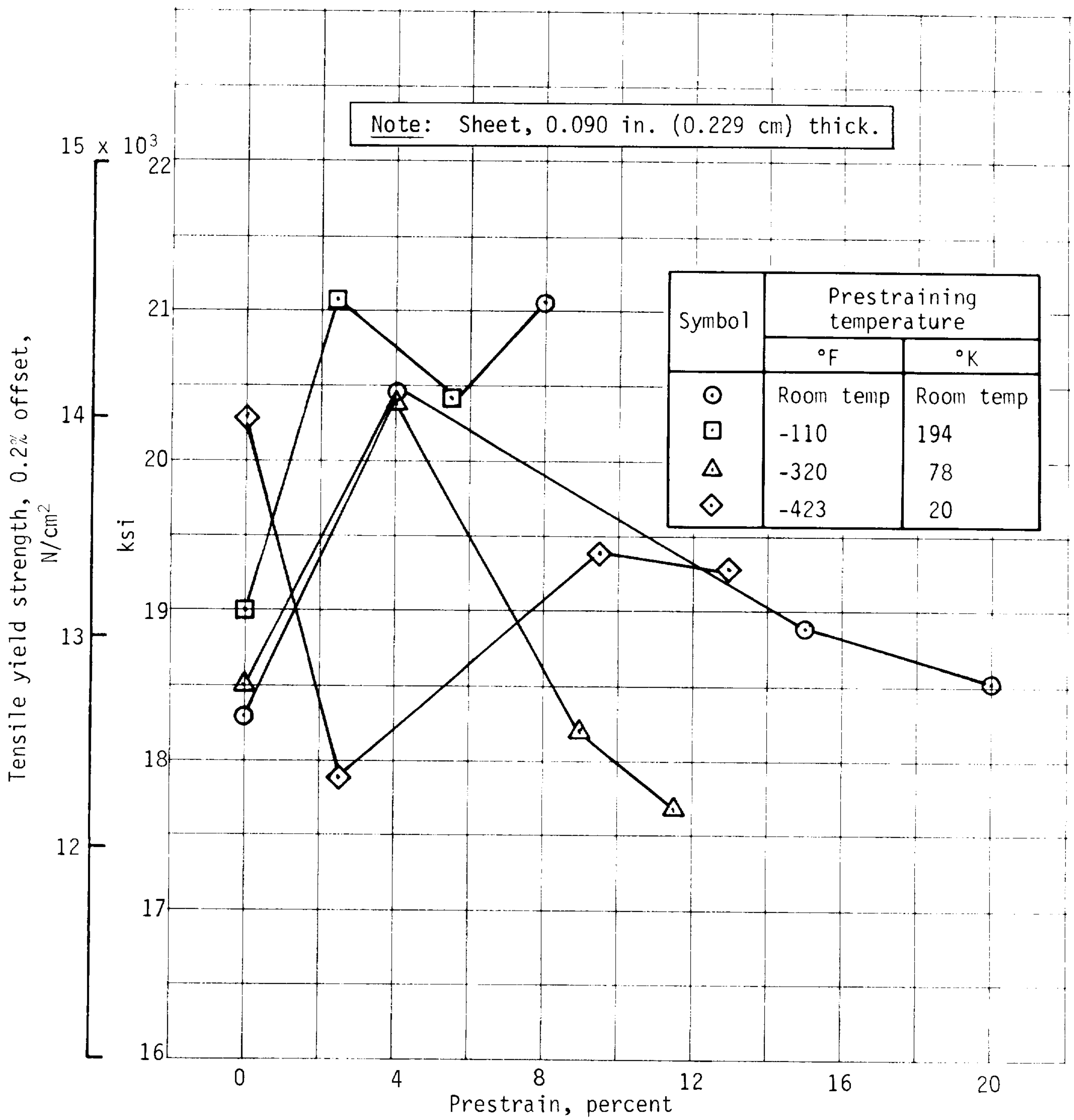


Figure 49.- Tensile Yield Strength of Prestrained LA141A-T7 Magnesium Alloy

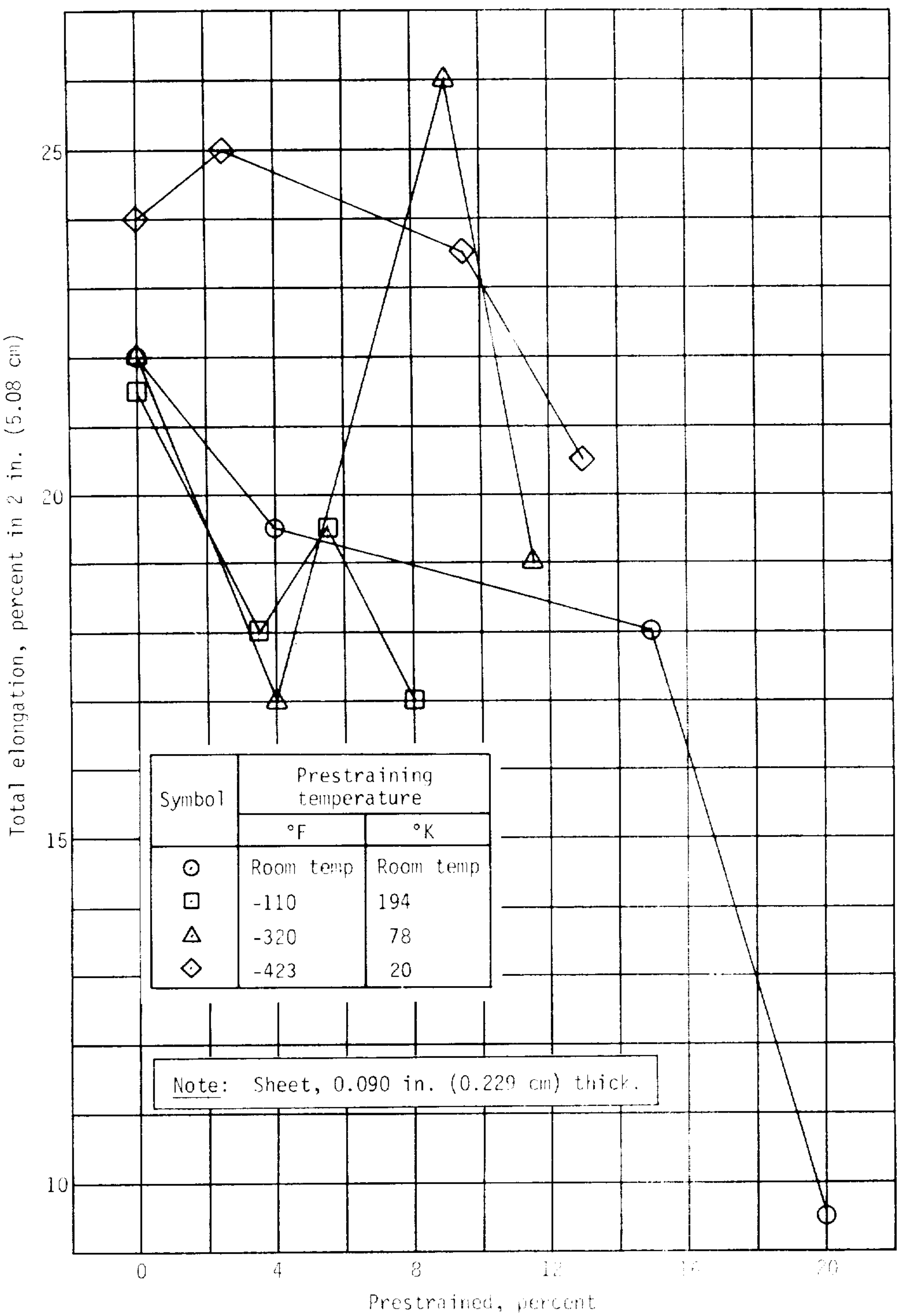
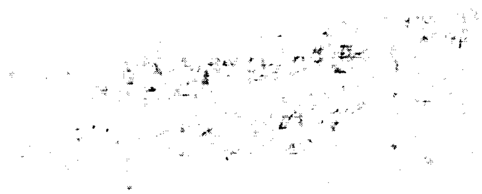


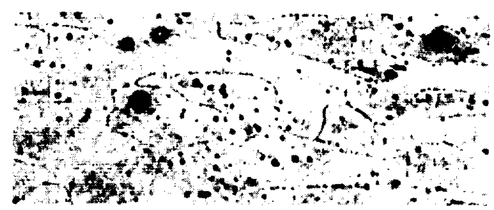
Figure 50.- Total Elongation of Prestrained LA141A-T7 Magnesium Alloy



(a) Soaked at Room Temperature, Unaged (150X)

(b) 4.0% Strained at Room Temperature, Aged 3 hr at 150°F (339°K) (250X)

(c) 4.0% Strained at -320°F (78°K), Aged 3 hr at 225°F (381°K) (150X)



(d) 9.0% Strain at -423°F (20°K), Aged 6 hr at 350°F (450°K) (250X)

Note: There were no observable changes to the microstructure due to straining at the different temperatures.

Etch: HNO_3 + Ethylene glycol

Figure 51.- Microstructure of LA141A Magnesium Alloy

Inconel 718

A sheet of annealed Inconel 718, 0.09x35x110 in. (0.229x89x279 cm) was procured to the requirements of General Electric material specfication B50 TF14A-S4. The chemical composition of the sheet material was:

Element	Percent by weight
Ni	54.40
Fe	18.36
Cr	17.39
Aℓ	0.60
Ti	1.01
Cb	4.93
Mn	0.04
C	0.04
Mo	2.93
S	0.007
Si	0.18
Ta	0.01
Co	0.03
P	0.01

Density: 0.297 lb/cu in; 8.21 gm/cc

The Inconel 718 specimens were prepared and processed in the normal manner described in Chapter III, with one exception. That exception was that the gage sections of the specimens were remachined after the specimens were strained. This operation was added to reduce the width, and thus the area, of the highly strained gage section to prevent out-of-gage failures during subsequent tensile tests.

A variety of aging treatments are recommended for Inconel 718. Some are single temperature treatments, while others are double temperature treatments. For this program two of the more easily controlled single temperature treatments were selected because they were considered equally valid for developing comparative straining response data. The Inconel 718 specimens that were aged were given one of the following treatments, as indicated.

1) The unstrained specimens were aged 16 hr at 1325°F (992°K) and air cooled;

2) Of each group of five specimens that had been given the same conditioning treatment (strained the same amount at the same temperature) four were aged 16 hr at 1275°F (964°K) and air cooled;

3) The rest of the strained specimens were aged 16 hr at 1325°F (992°K) and air cooled.

The specimens were cleaned and coated with a protective lacquer before aging.

The results of the tests conducted on the Inconel 718 specimens are given in figures 52 through 60, and are listed in tables 16 and 17 of the Appendix. Figure 61 shows photomicrographs of the microstructure of this material in various conditions.

The uniform strain capability of Inconel 718 is greater at the cryogenic temperatures than at room temperature, 49% at room temperature, 55% at -110°F (194°K), 60% at -320°F (78°K), and 57% at -423°F (20°K). Because Inconel 718 can be strained greater amounts at the cryogenic temperatures than at room temperature, it is possible to develop higher strengths at those temperatures than at room temperature. This, however, is the only advantage to be gained by cryostraining Inconel 718, and it is a small advantage. When Inconel 718 was strained 48.5% (80% of its uniform strain capability) at -320°F (78°K), it had an ultimate tensile strength of 244 200 psi (168 400 N/cm^2), a tensile yield strength of 239 200 psi (164 900 N/cm^2), and an elongation of 8.5%. By comparison, after it was strained 39.0% at room temperature (80% of its uniform strain capability), it had an ultimate tensile strength of 228 500 psi (157 600 N/cm^2), a tensile yield strength of 223 600 psi (154 200 N/cm^2), and an elongation of 13.5%. So, the additional 9.5% strain imparted to the material at -320°F increased both the ultimate tensile strength and the tensile yield strength of the material approximately 7%, while its elongation was reduced from 13.5% to 8.5%.

Judging the response of Inconel 718 to cryostraining on the basis of equal strains, cryostraining offers no advantage at all. A given amount of strain will develop essentially the same tensile properties regardless of whether the material is strained at room temperature, -110°F (194°K), -320 °F (78°K), or -423°F (20°K).

Cryostraining is not a practical method of strengthening Inconel 718.

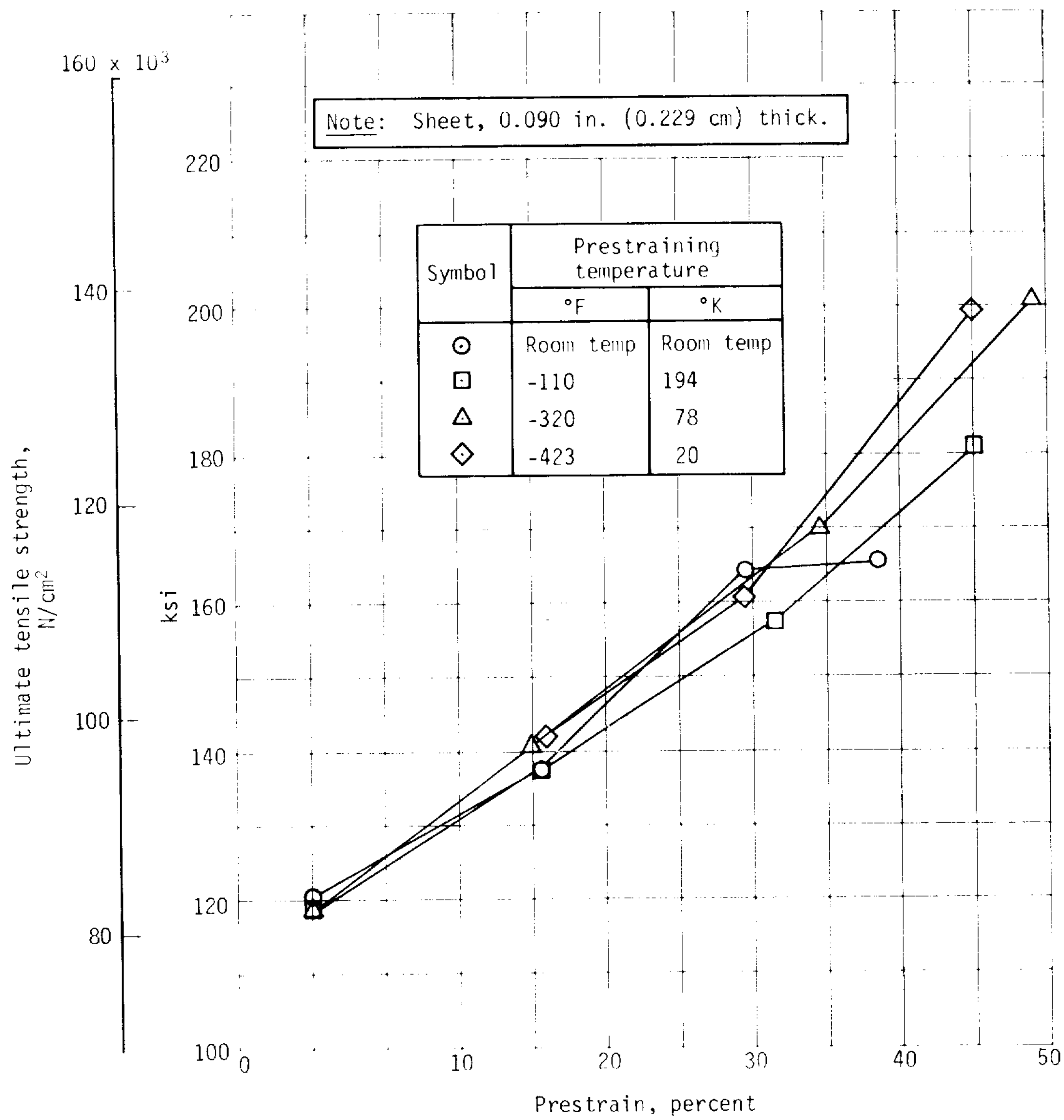


Figure 52.- Ultimate Tensile Strength of Prestrained Inconel 718

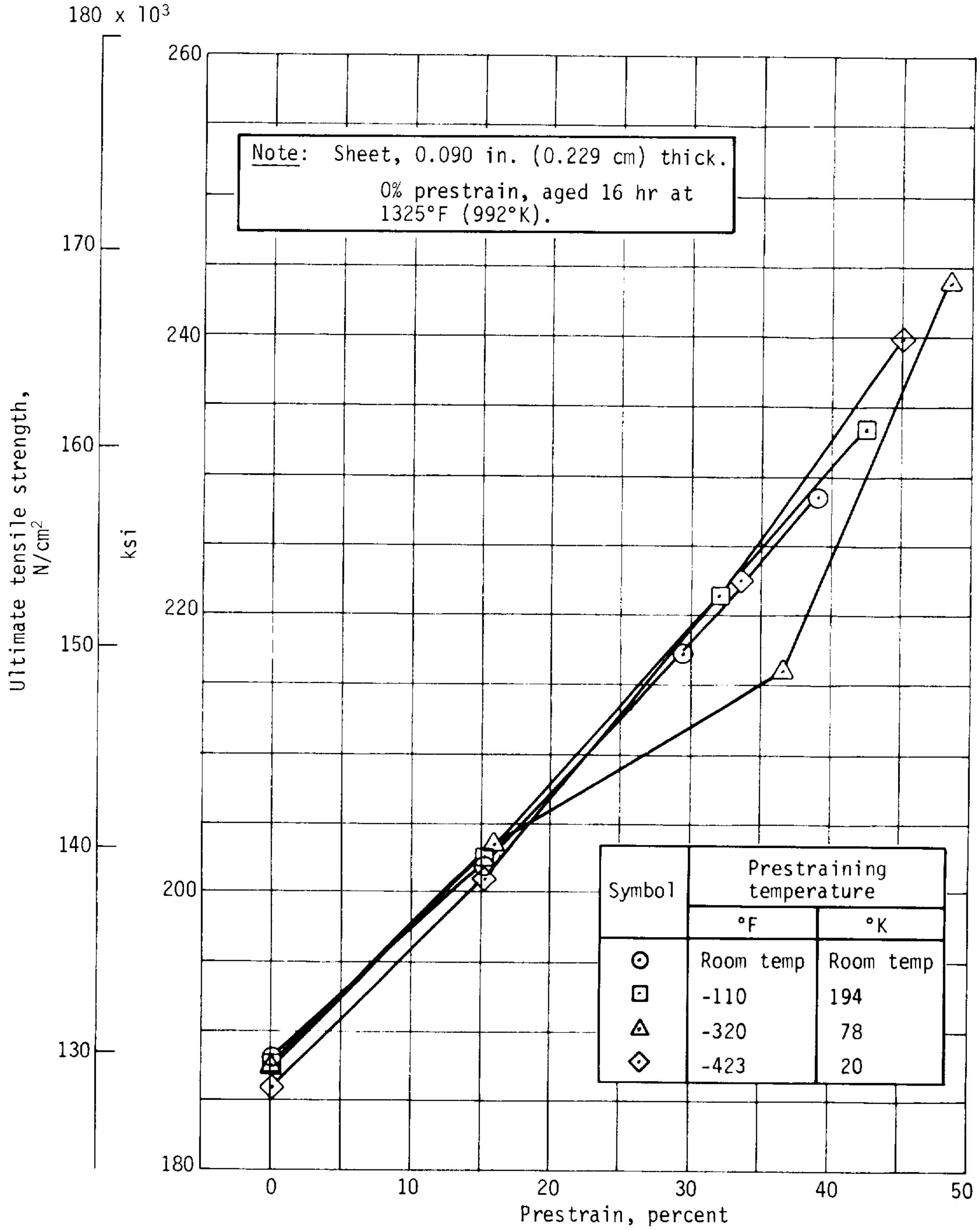


Figure 53.- Ultimate Tensile Strength of Prestrained Inconel 718, Aged 16 hr at 1275°F (964°K)

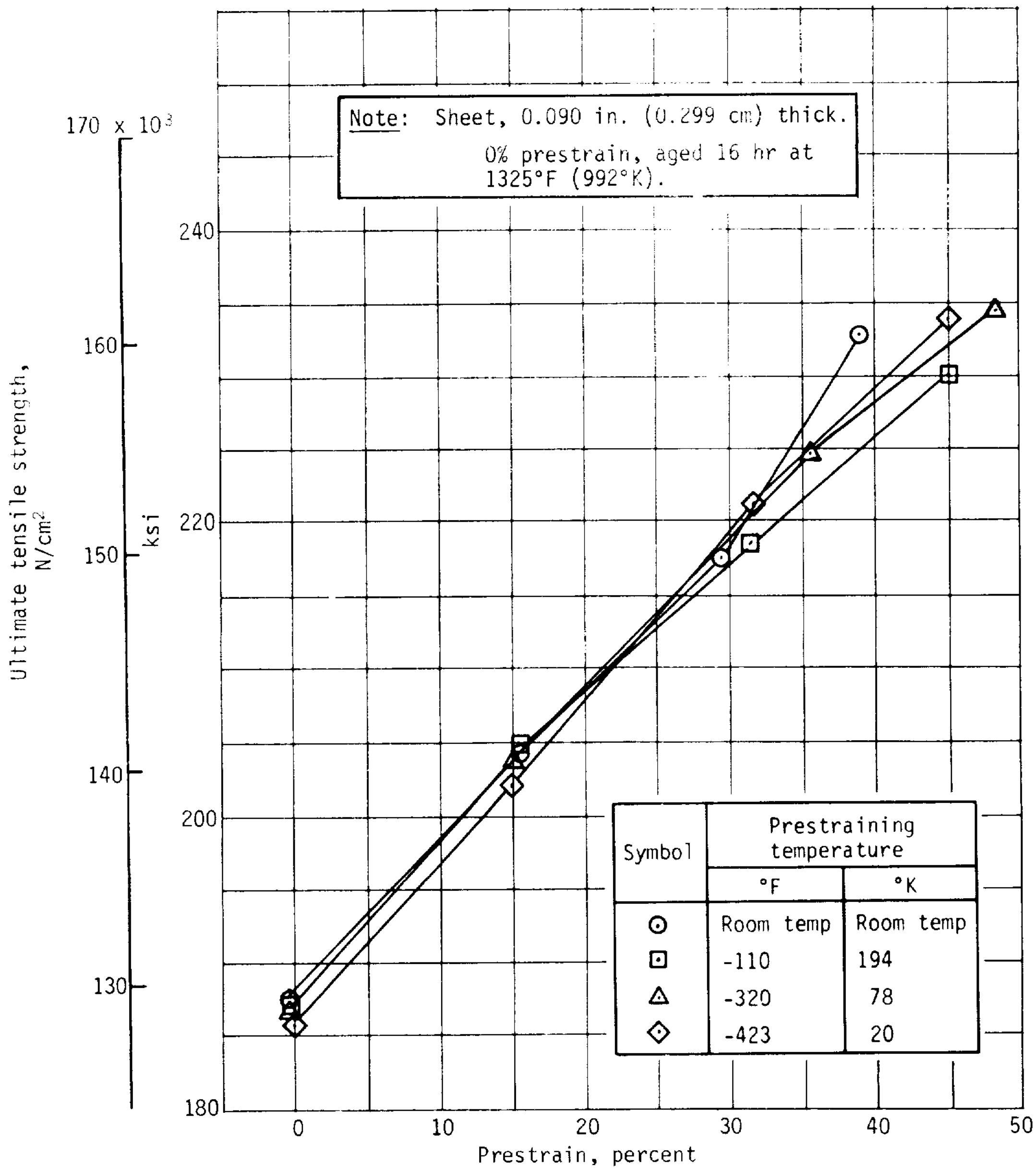


Figure 54.- Ultimate Tensile Strength of Prestrained Inconel 718, Aged 16 hr at 1325°F (992°K)

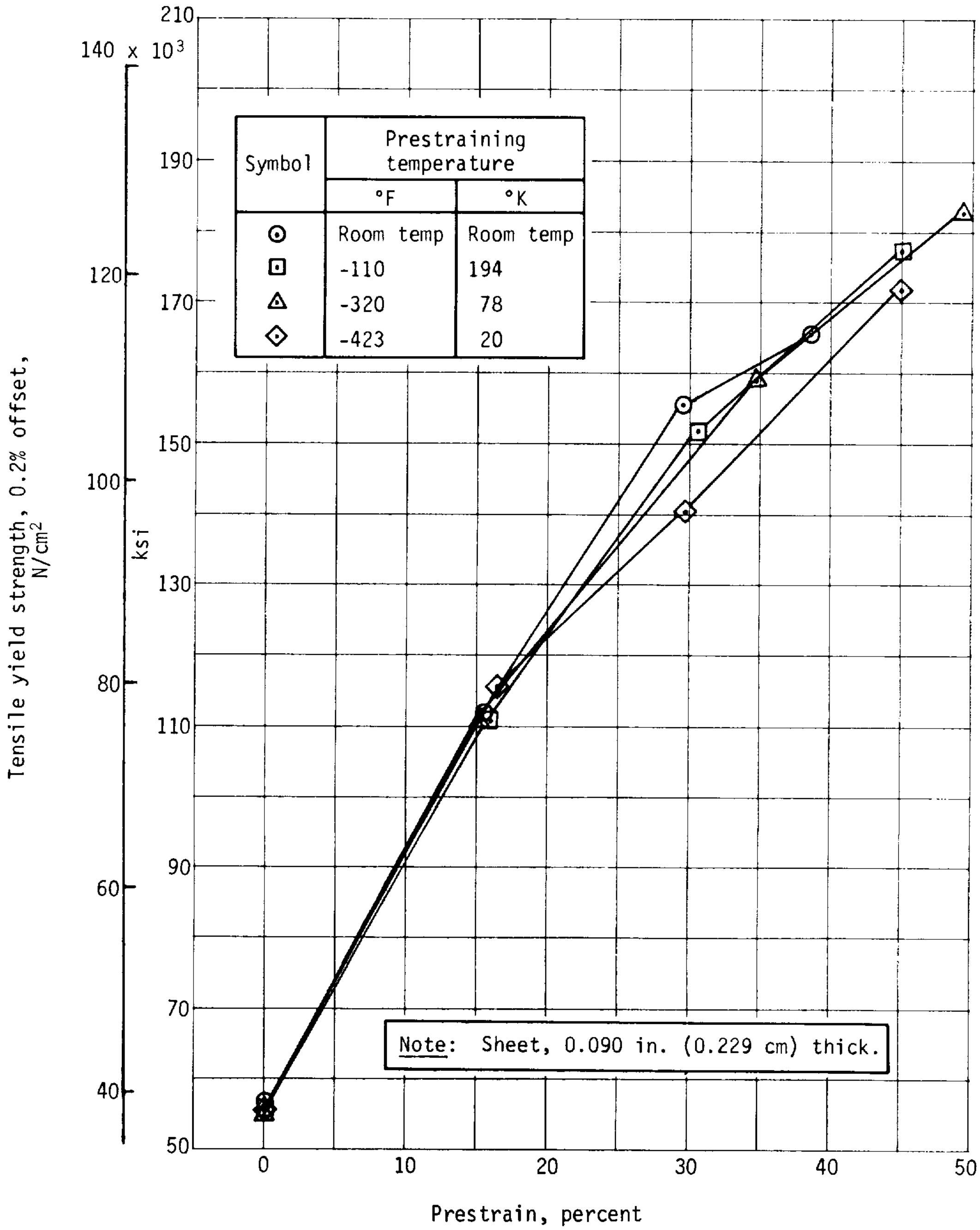


Figure 55.- Tensile Yield Strength of Prestrained Inconel 718

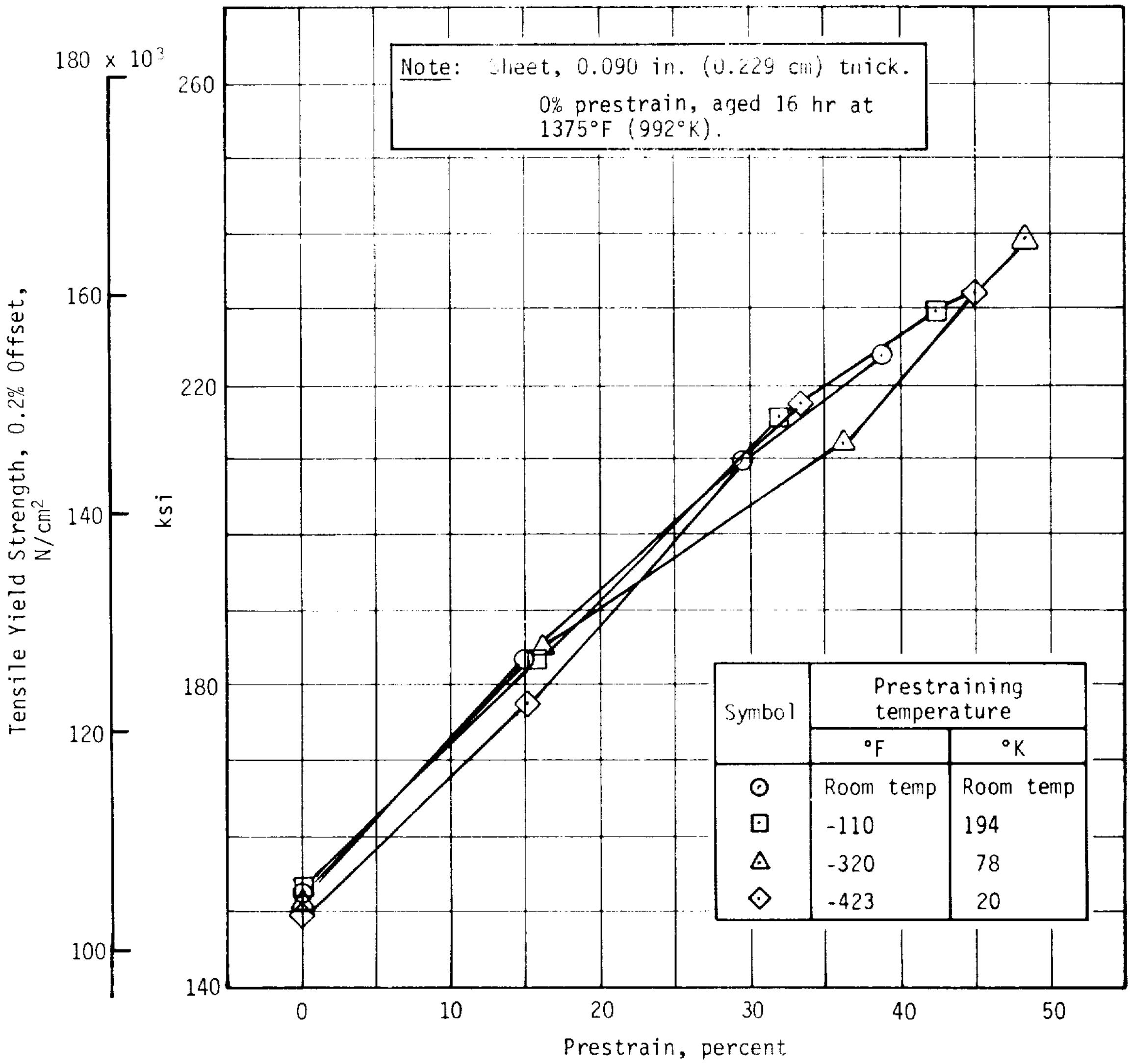


Figure 56.- Tensile Yield Strength of Prestrained Inconel 718, Aged 16 hr at 1275°F (964°K)

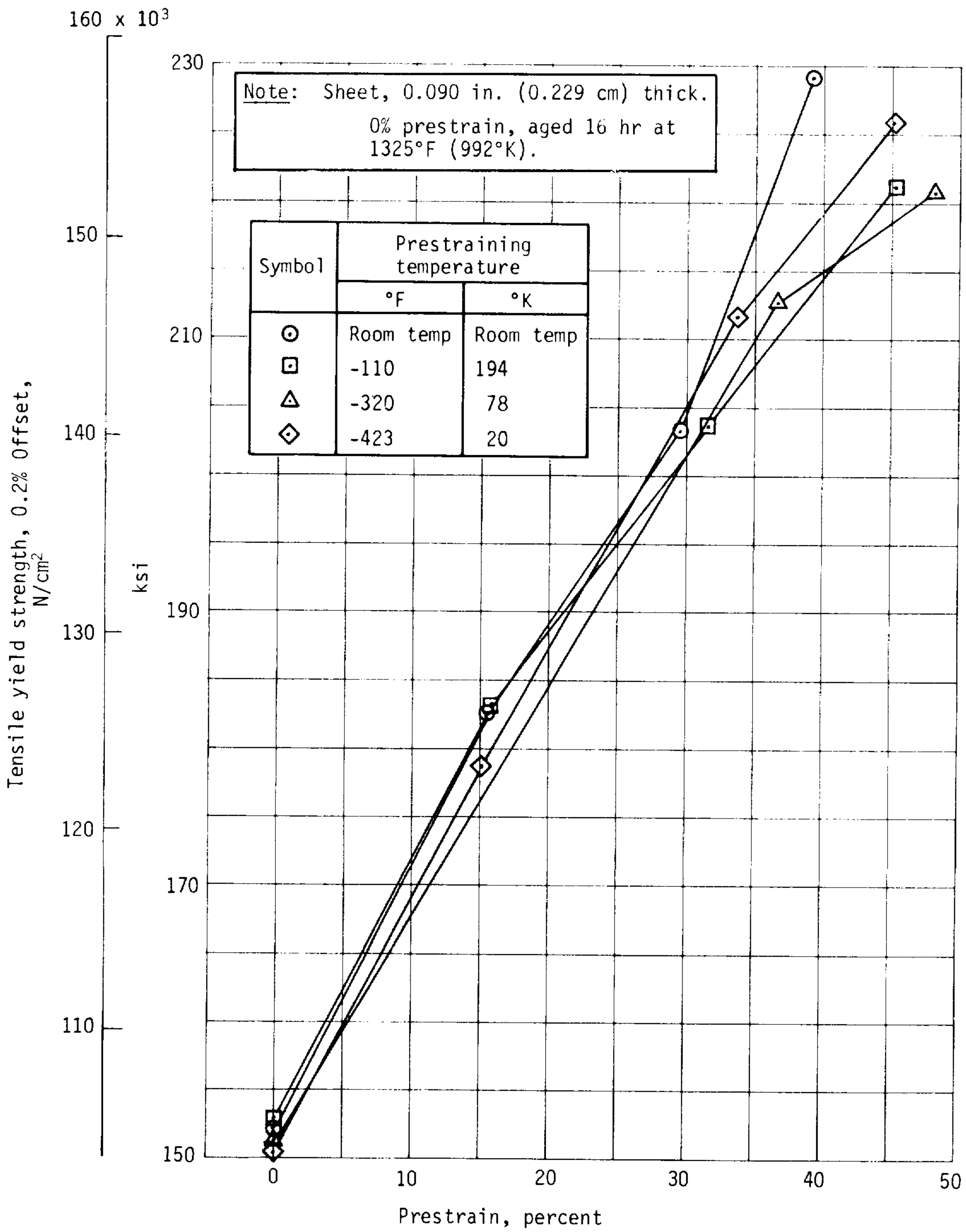


Figure 57.- Tensile Yield Strength of Prestrained Inconel 718, Aged 16 hr at 1325°F (992°K)

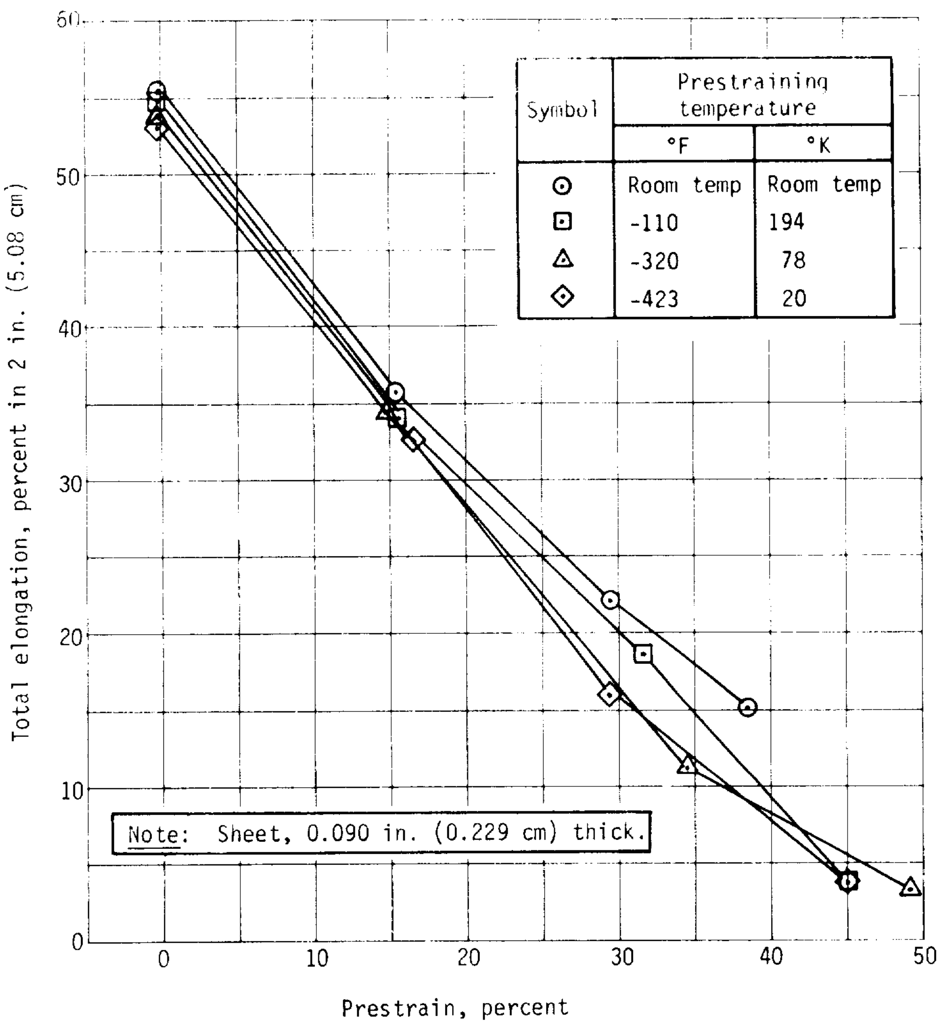


Figure 58.- Total Elongation of Inconel 718

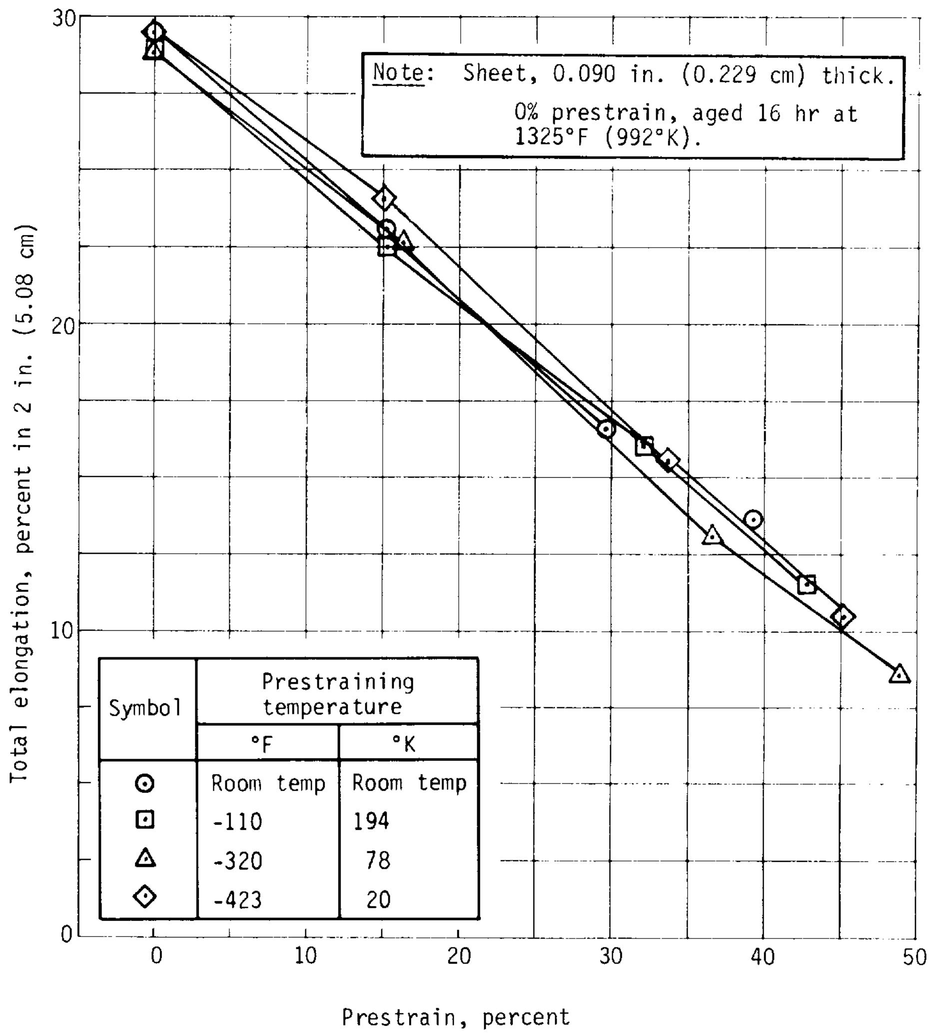


Figure 59.- Total Elongation of Prestrained Inconel 718, Aged 16 hr at 1275°F (964°K)

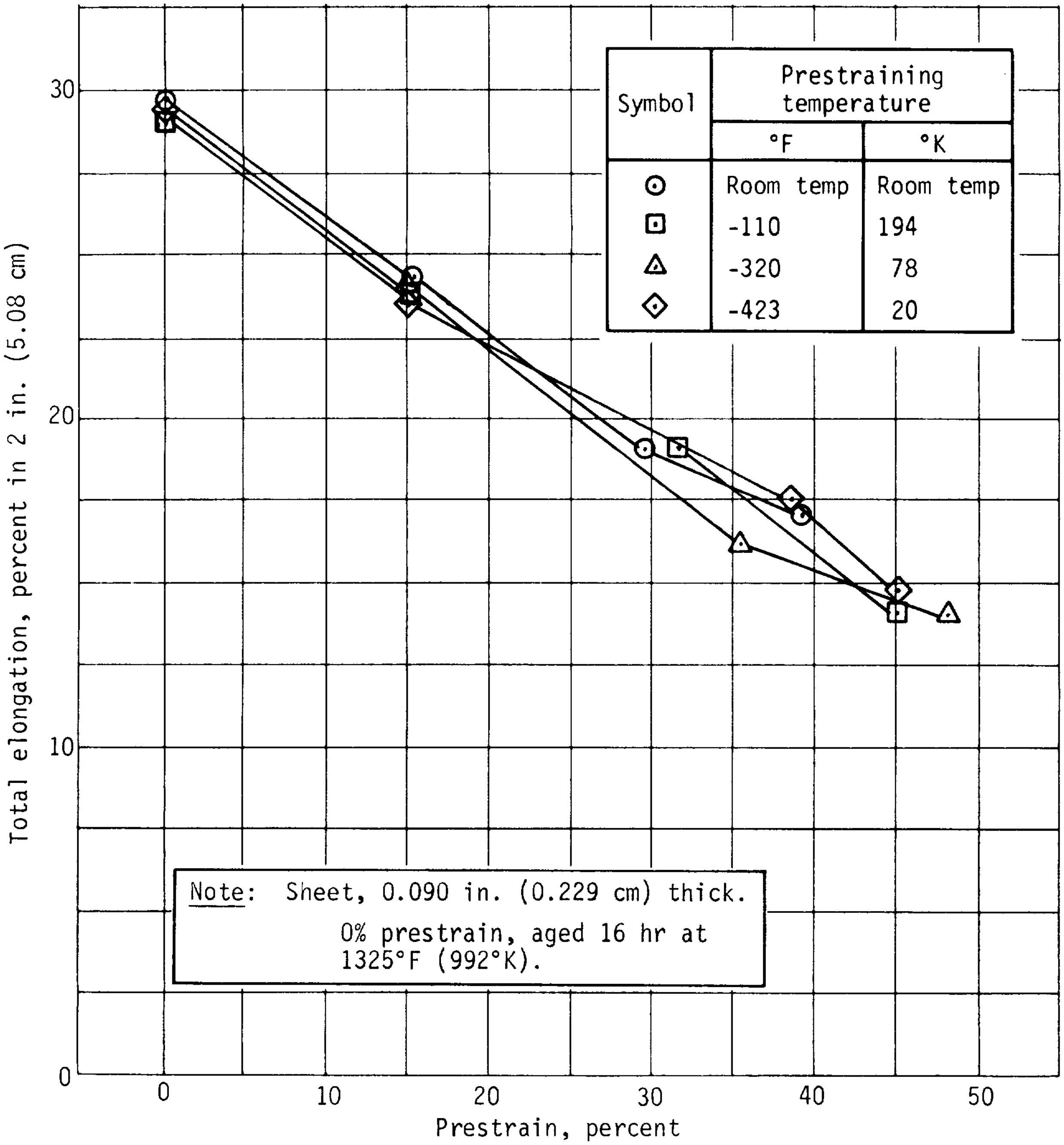


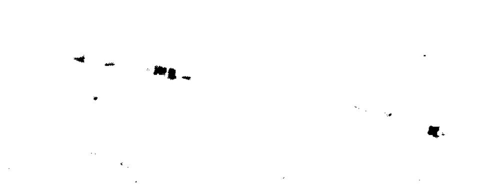
Figure 60.- Total Elongation of Prestrained Inconel 718, Aged 16 hr at 1325°F (992°K)

(a) Room Temperature Soak, Unaged

(b) Room Temperature Soak, Aged 16 hr at 1325°F (992°K)

(c) 38.5% Strain at Room Temperature, Aged 16 hr at 1325°F (992°K)

(d) 45.0% Strain at -423°F (20°K), Aged 16 hr at 1325°F (992°K)



(e) 42.5% Strain at -110°F (194°K), Aged 16 hr at 1325°F (992°K)

(f) 48.0% Strain at -320°F (78°K), Aged 16 hr at 1325°F (992°K)

Note:	The grain boundaries of the aged structures are more distinct than those of the unaged structure. The strained structures show some twinning.

Electroetch: HCL + Methanol 250X

Figure 61.- Microstructure of Inconel 718 Nickel Alloy

Nickel 440

Nickel 440 was procured in strip form. A total of 60 ft of 0.062 in. thick by 3 in. wide (1828x0.157x8 cm) strip was procured to commercial requirements. The chemical composition of this materials was:

Element	Percent by weight
Be	2.30
Ti	0.35
Si	0.23
Ni	Balance

Density: 0.302 lb/cu in.; 8.86 gm/cc

The Nickel 440 specimens were prepared and processed in the normal manner except that they were made from strip rather than sheet. Also, after Nickel 440 specimens were strained they were remachined to reduce the width and therefore the area of the highly strained gage section. This was done to prevent out-of-gage failures during tensile tests.

Nickel 440 is an age hardenable nickel alloy. The aging cycle selected for the unstrained specimens was 1.5 hr at 970°F (795°K). Strained specimens were aged 1.5 hr at 930°F (773°K).

The results of the tests conducted on Nickel 440 specimens are given in figures 62 through 67, and are listed in tables 18 and 19 of the Appendix. Figure 68 shows photomicrographs of Nickel 440 microstructure in various conditions.

The Nickel 440 strip material was found to have a uniform strain capability of 37.0% at room temperature, 42.0% at -110°F (194°K), 43.0% at -320°F (78°K), and 50.0% at -423°F (20°K).

Exposure to the cryogenic temperatures did not change the room temperature tensile strength of the Nickel 440 strip. Also, the temperature at which this alloy was strained did not significantly influence the strength developed by a given amount of strain. Whether the material was strained at room temperature or at one of the cryogenic temperatures, a given amount of strain developed essentially the same tensile properties. The only advantage gained by straining Nickel 440 at cryogenic temperatures is that greater strains are possible at cryogenic temperatures than at room temperature. Consequently, the greater strain hardening possible at the cryogenic temperatures permits the development at higher strengths at those temperatures than at room temperature.

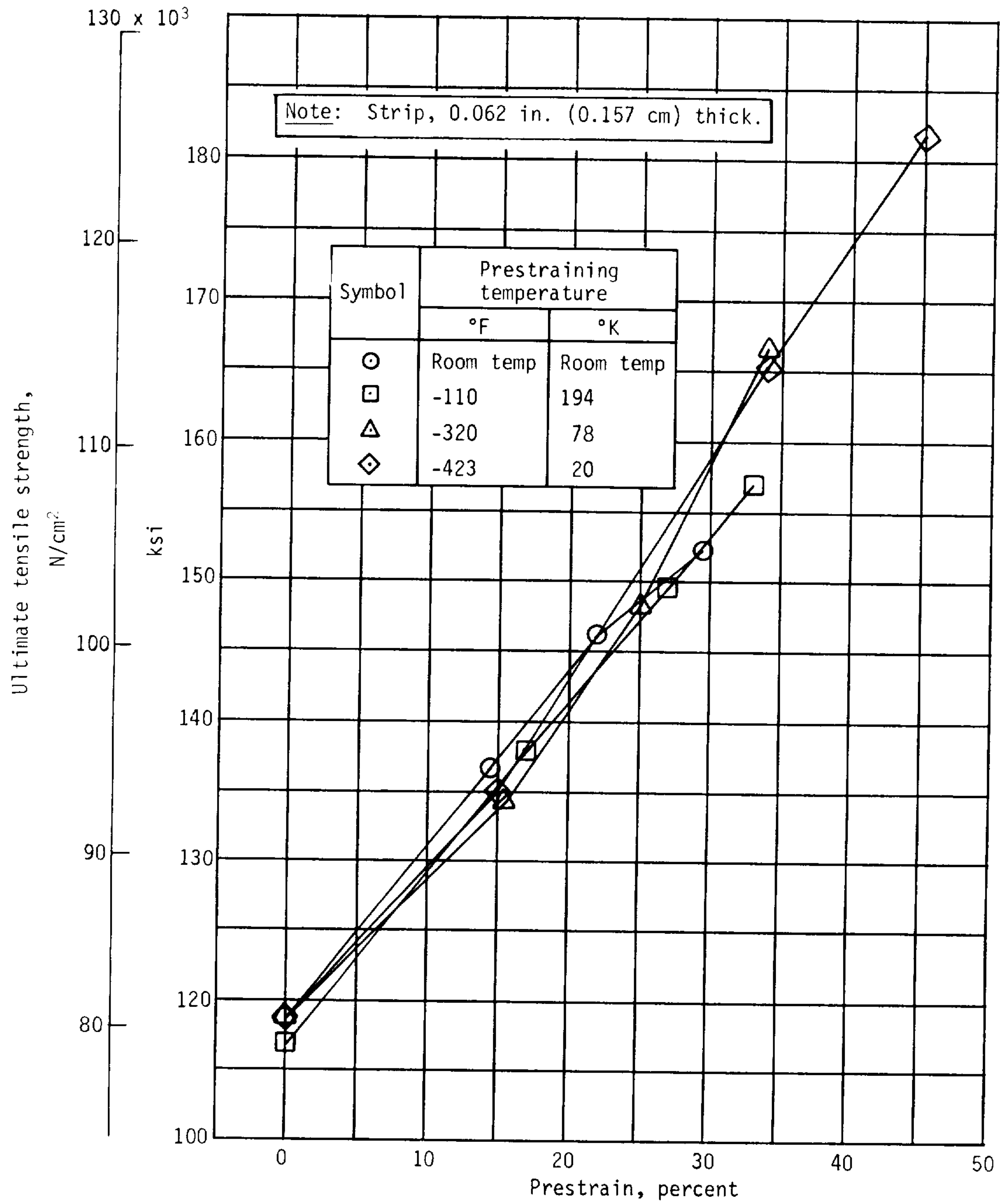


Figure 62.- Ultimate Tensile Strength of Prestrained Nickel 440

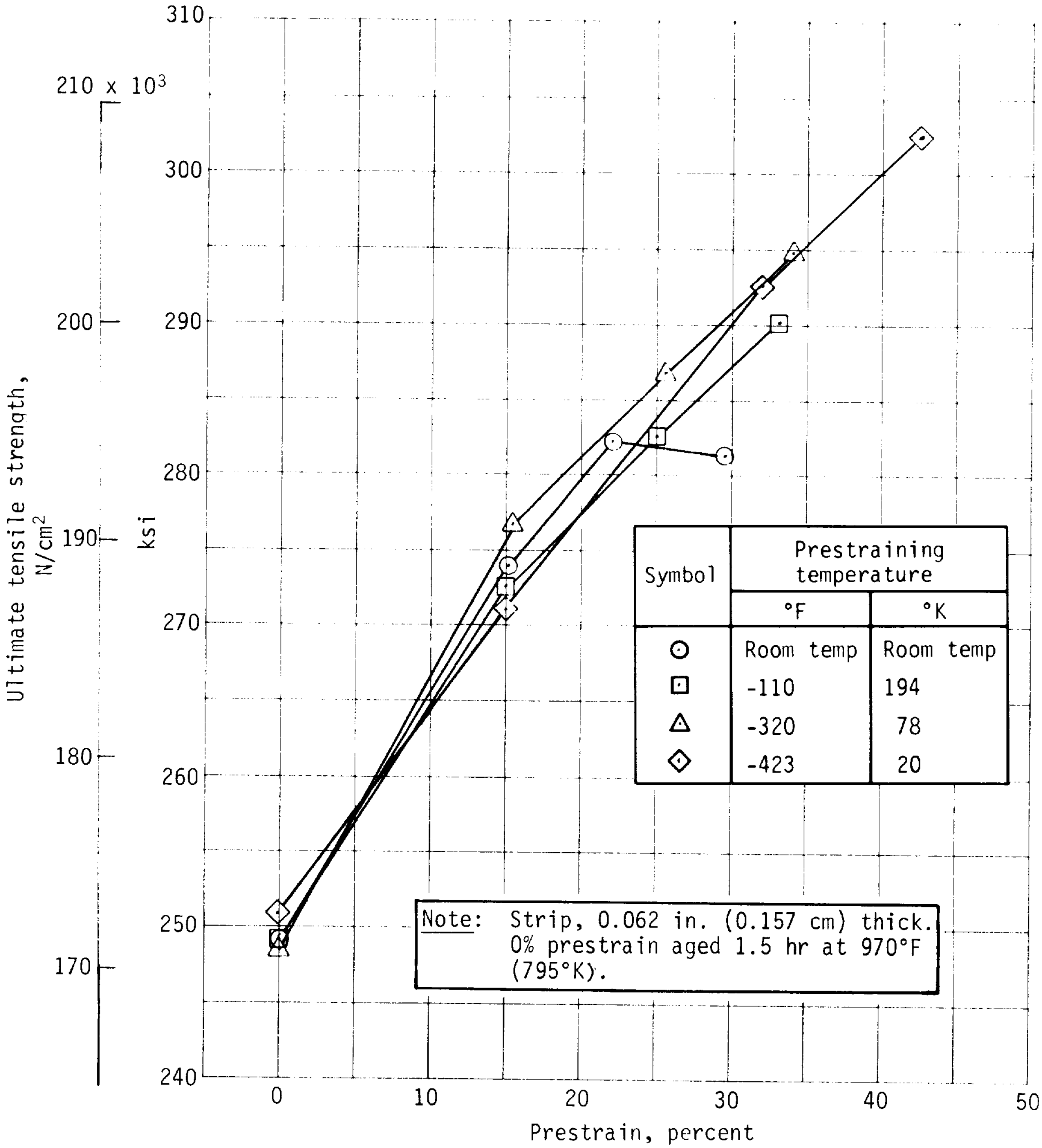


Figure 63.- Ultimate Tensile Strength of Prestrained Nickel 440 Aged 1.5 hr at 930°F (773°K)

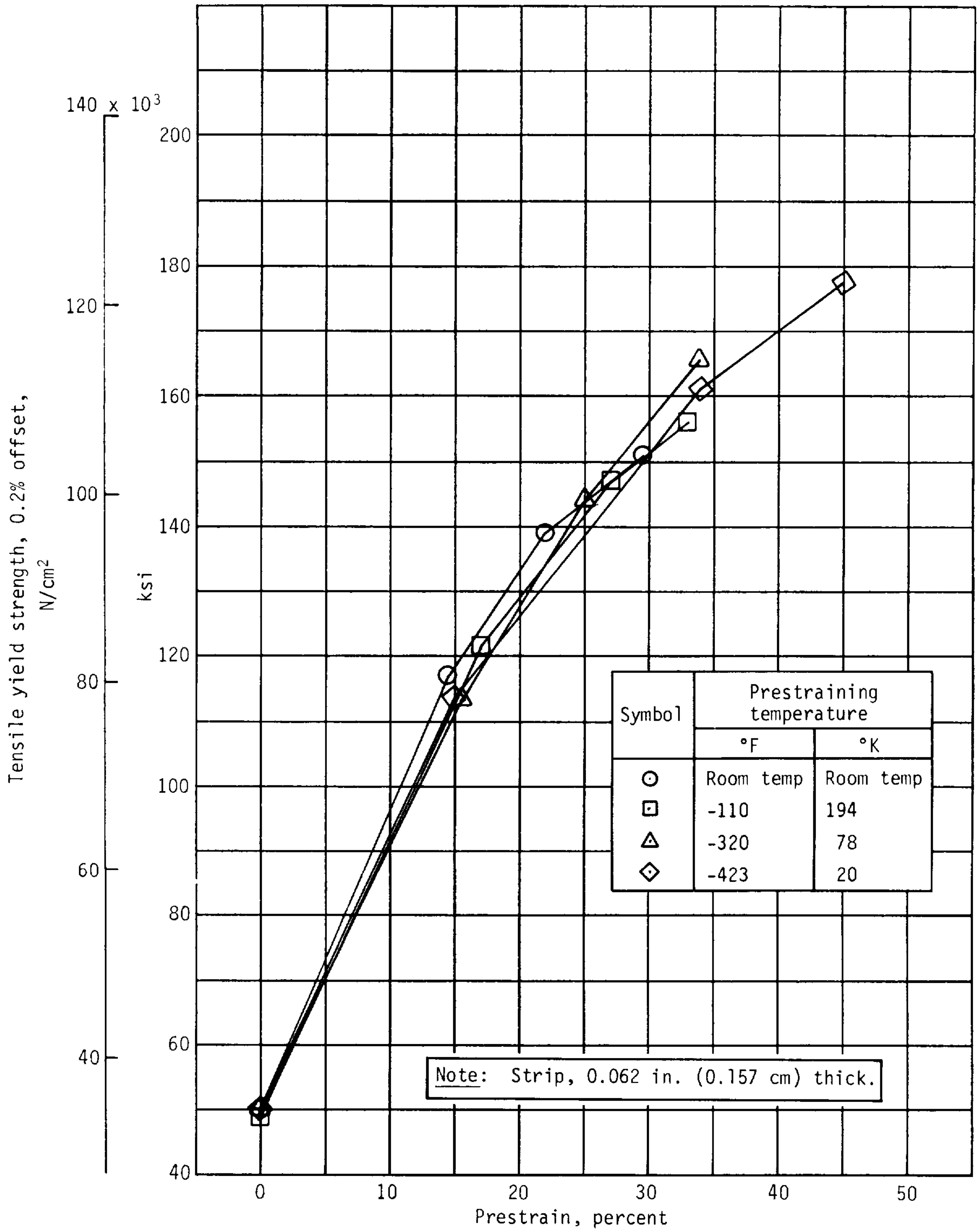


Figure 64.- Tensile Yield Strength of Prestrained Nickel 440

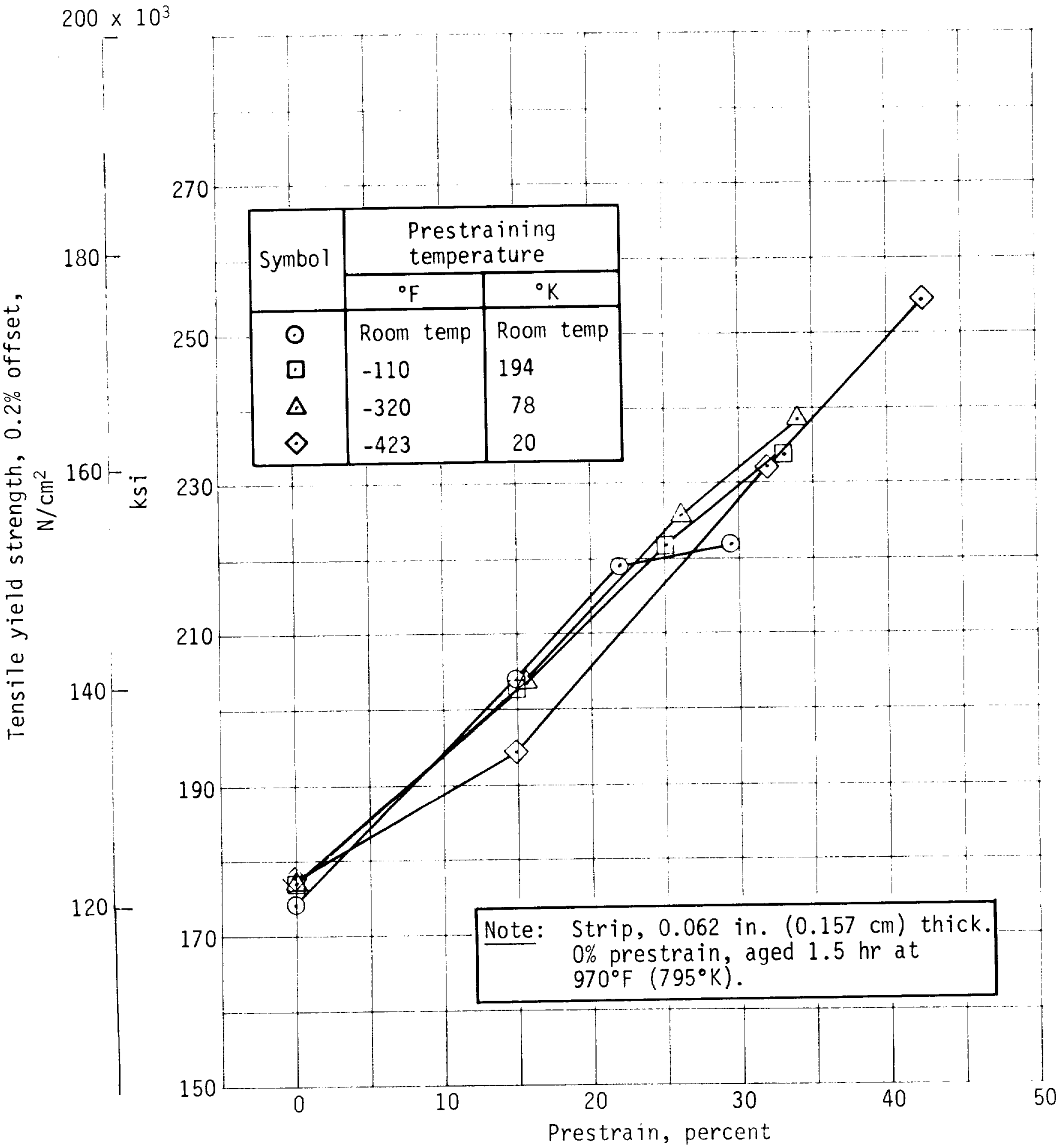


Figure 65.- Tensile Yield Strength of Prestrained Nickel 440, Aged 1.5 hr at 930°F (773°K)

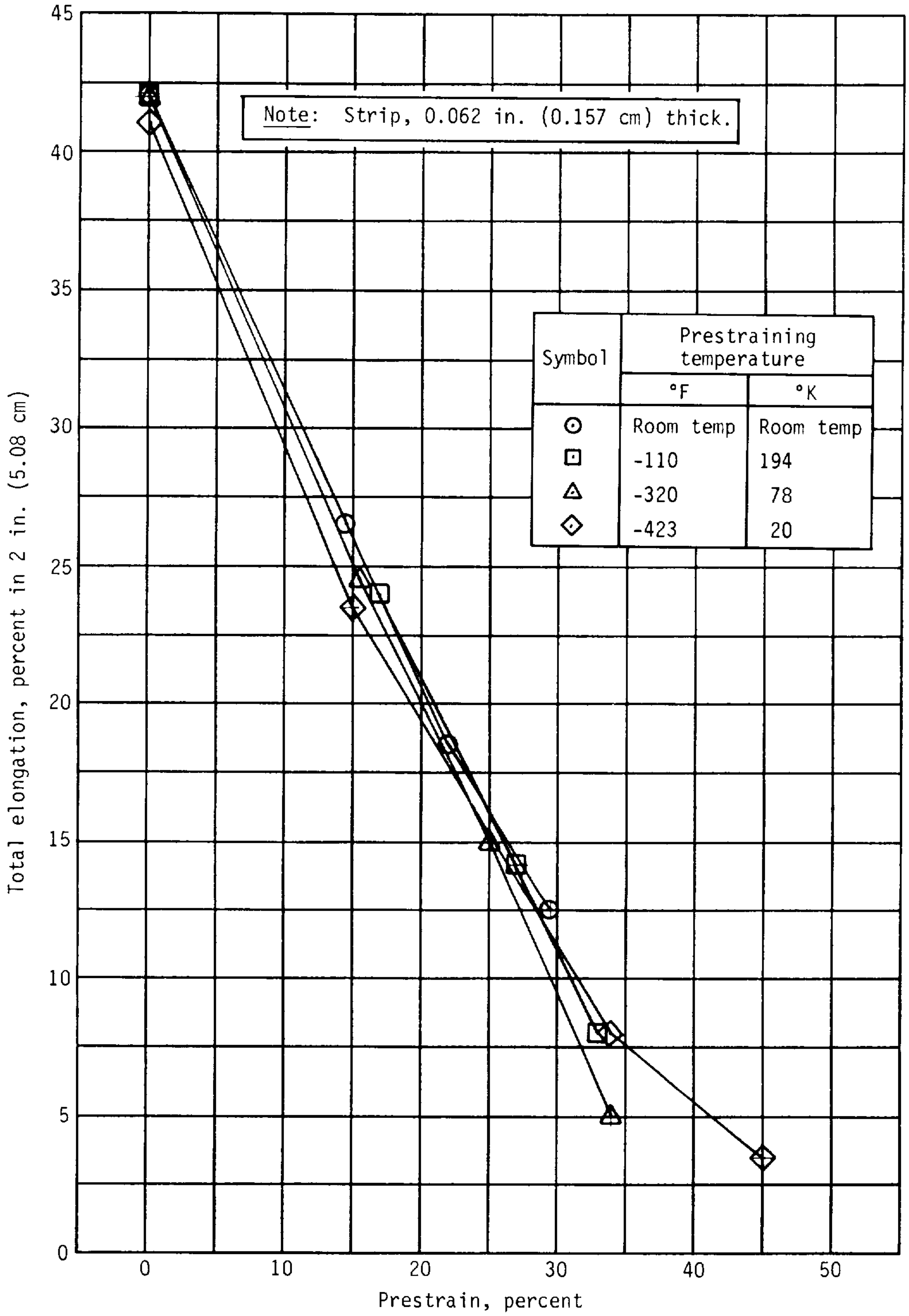


Figure 66.- Total Elongation of Prestrained Nickel 440

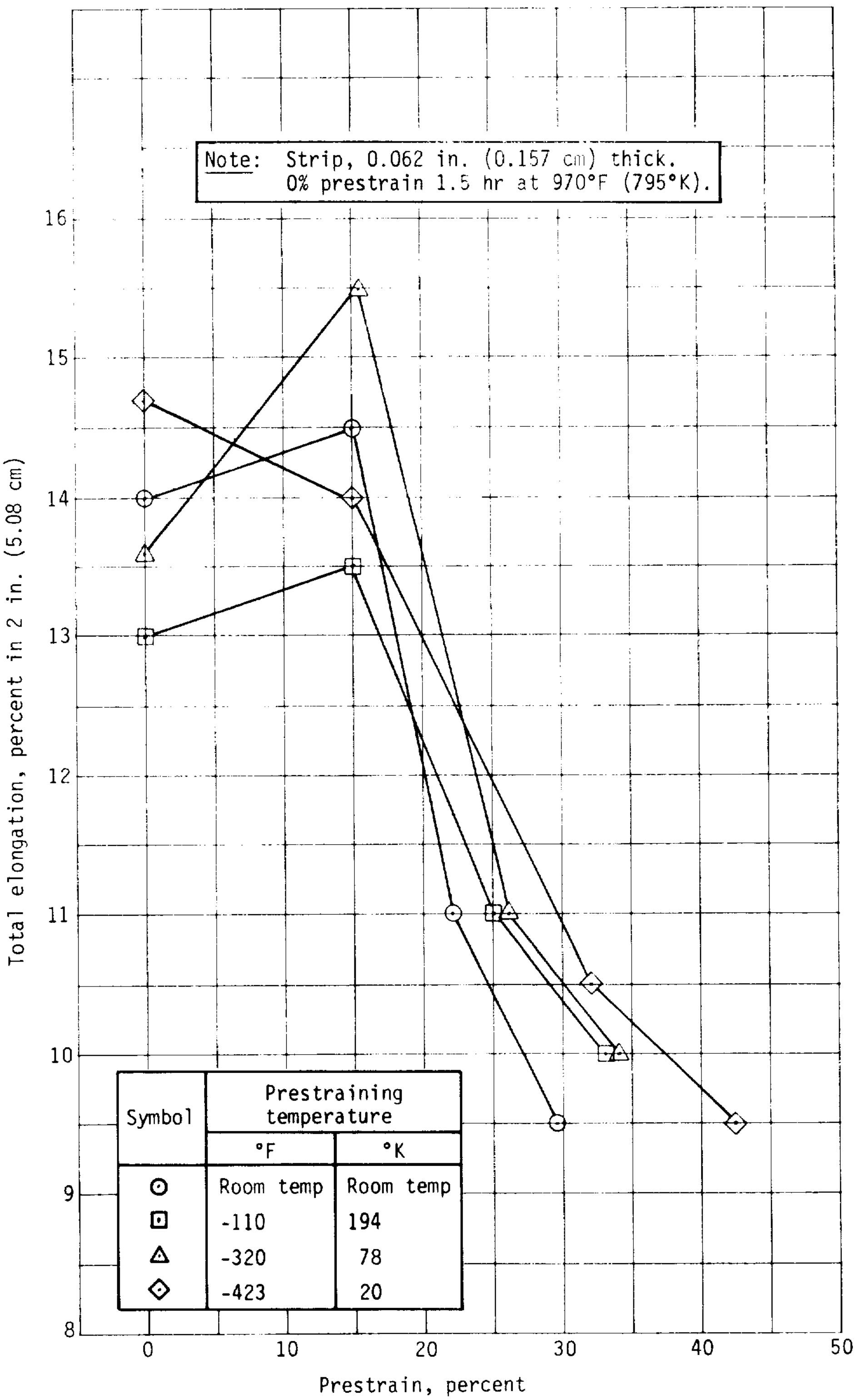
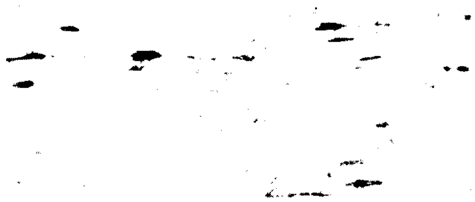


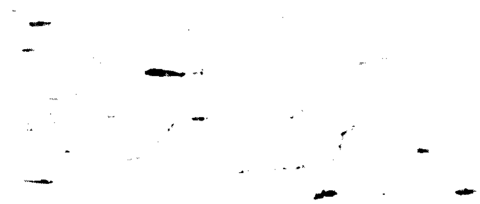
Figure 67.- Total Elongation of Prestrained Nickel 440, Aged 1.5 hr at 930°F (773°K)

(a) Soaked at Room Temperature, Unaged

(b) Soaked at Room Temperature, Aged 1.5 hr at 930°F (773°K)

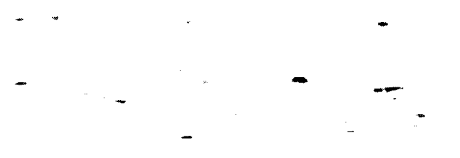


(c) 33.0% Strain at -110°F (194°K), Aged 1.5 hr at 970°F (795°K)



(d) 42.5% Strain at -423°F (20°K), Aged 1.5 hr at 970°F (795°K)

(e) 29.5% Strain at Room Temperature, Aged 1.5 hr at 970°F (795°K)



(f) 34.0% Strain at -320°F (78°K), Aged 1.5 hr at 970°F (795°K)

<u>Note</u>: Neither straining at temperature nor aging produced a distinguishable affect on the microstructure.

Electroetch: HCL + Methanol 200X

Figure 68.- Microstructure of Nickel 440

A-286 Corrosion Resistant Steel

A sheet of annealed A-286 corrosion resistant steel measuring 0.055x36x114 in. (0.140x91x290 cm) was procured to the requirements of material specification AMS 5525B. The chemical composition of this sheet was:

Element	Percent by Weight
C	0.058
Mn	1.58
P	0.022
S	0.012
Si	0.67
Cr	14.70
Ni	25.63
Cu	0.29
Ti	2.22
Mo	1.21
Aℓ	0.06
V	0.48
B	0.0056
Fe	Balance

Density: 0.286 lb/cu in.; 7.92 gm/cc

The normal proceudres described in Chapter III were used to prepare and process the A-286 specimens.

A-286 is an austenitic precipitation hardening stainless steel. This alloy can be strengthened by cold work, by thermal treatment, or by combination cold work-aging treatments. Regarding aging treatments, for maximum strengthening of cold worked A-286 it is necessary to lower the aging temperature relative to the amount of work imparted to the material. The aging treatments used were selected after reviewing available data. For the unstrained specimens the normal aging treatment of 1325°F (992°K) for 16 hr was selected. Two aging treatments were selected for the strained specimens, one that was best for highly strained specimens and another that was more appropriate for the lesser strained specimens. The A-286 specimens that were aged were given one of the following treatments, as indicated:

1) The unstrained specimens were aged 16 hr at 1325°F (992°K) and air cooled;
2) Of each group of five specimens that had been given the same conditioning treatment (strained the same amount at the same temperature) four were aged 16 hr at 1150°F (894°K) and air cooled;
3) The rest of the strained specimens were aged 16 hr at 1250°F (951°K) and air cooled.

Before aging, the specimens were thoroughly cleaned and coated with a protective lacquer.

The results of the tests conducted on the A-286 specimens are given in figures 69 through 77, and listed in tables 20 and 21 of the Appendix. Figure 78 shows photomicrographs of the microstructure of A-286 in various conditions.

The A-286 sheet material was found to have a higher uniform strain capability at the cryogenic temperatures than at room temperature; specifically, 36.0% at room temperature, 44% at -110°F (194°K), 72.5% at -320°F (78°K), and 65% at -423°F (20°K).

Exposure to the cryogenic temperatures had no affect on the room temperature tensile properties of A-286. Also, the temperature at which the material was strained did not significantly affect the resultant properties. A given amount of strain produced essentially the same properties, regardless of the temperature at which the material was strained.

The only advantage that can be gained from cryostraining A-286 is that at cryogenic temperatures greater strains are possible than at room temperature; therefore, since this alloy strain hardens, higher strengths can be developed at the cryogenic temperatures than at room temperature. Consider the specimens that were strained to 80% of their uniform strain capability at temperature. The specimen strained at room temperature were strained 29.0%. After aging at 1250°F (951°K) the material had an ultimate tensile strength of 184 100 psi (126 900 N/cm^2) a tensile yield strength at 173 800 psi (119 800 N/cm^2) and an elongation at 11.5%. The specimens strained 57.5% at -320°F (78°K), after aging at 1150°F (895°K), had an ultimate tensile strength of 219 200 psi (151 100 N/cm^2), a tensile yield strength at 216 600 psi (149 300 N/cm^2) and an elongation of 5.5%. The additional straining at -320°F (78°K), 28.5%, resulted in a 19% increase in the ultimate tensile strength, a 24.6% increase in tensile yield strength, while elongation was reduced by somewhat more than 50%. These are rather sizeable changes. But, only two aging treatments were used for the strained specimens, so caution must be exercised in analyzing these reactions. For example, the test results indicate that the material that was strained 57.5% at -320°F (78°K) and then aged for 16 hr at 1250°F (951°K) was overaged. Conversely, the results indicate that the material strained 29.0% at room temperature and aged for 16 hr at 1150°F (894°K) was underaged. It is possible that neither of the aging treatments is the best for either of these conditions. However, considering the data available, two facts emerge:

1) For strains of 36% (the room temperature uniform strain limit) or less there is no advantage to be gained from cryostraining A-286;

2) At cryogenic temperatures A-286 can be strained more than 36%, and the greater strains will develop higher tensile strengths. For some applications this method of strengthening A-286 might be feasible.

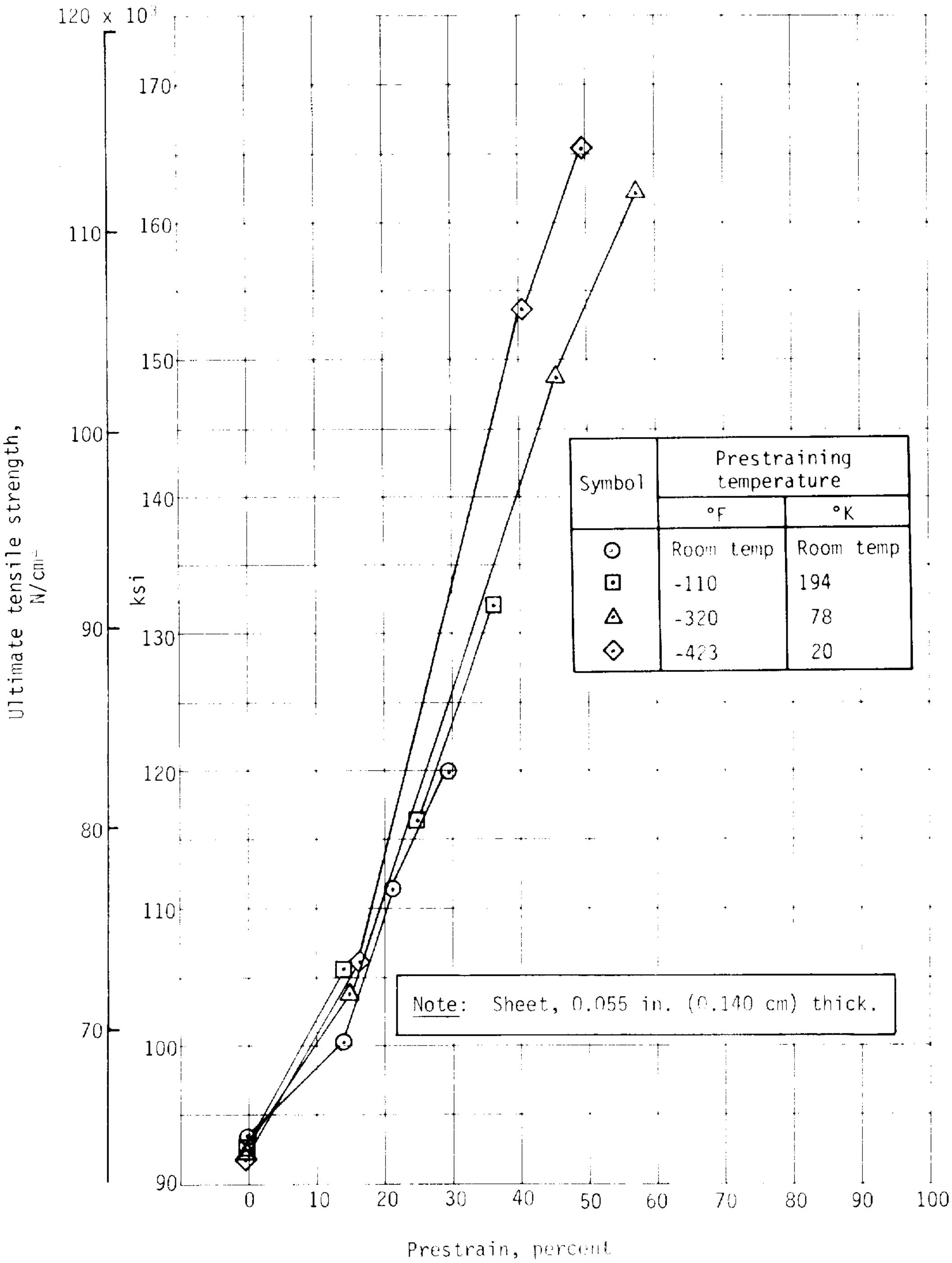


Figure 69.- Ultimate Tensile Strength of Prestrained A-286 Corrosion Resistant Steel

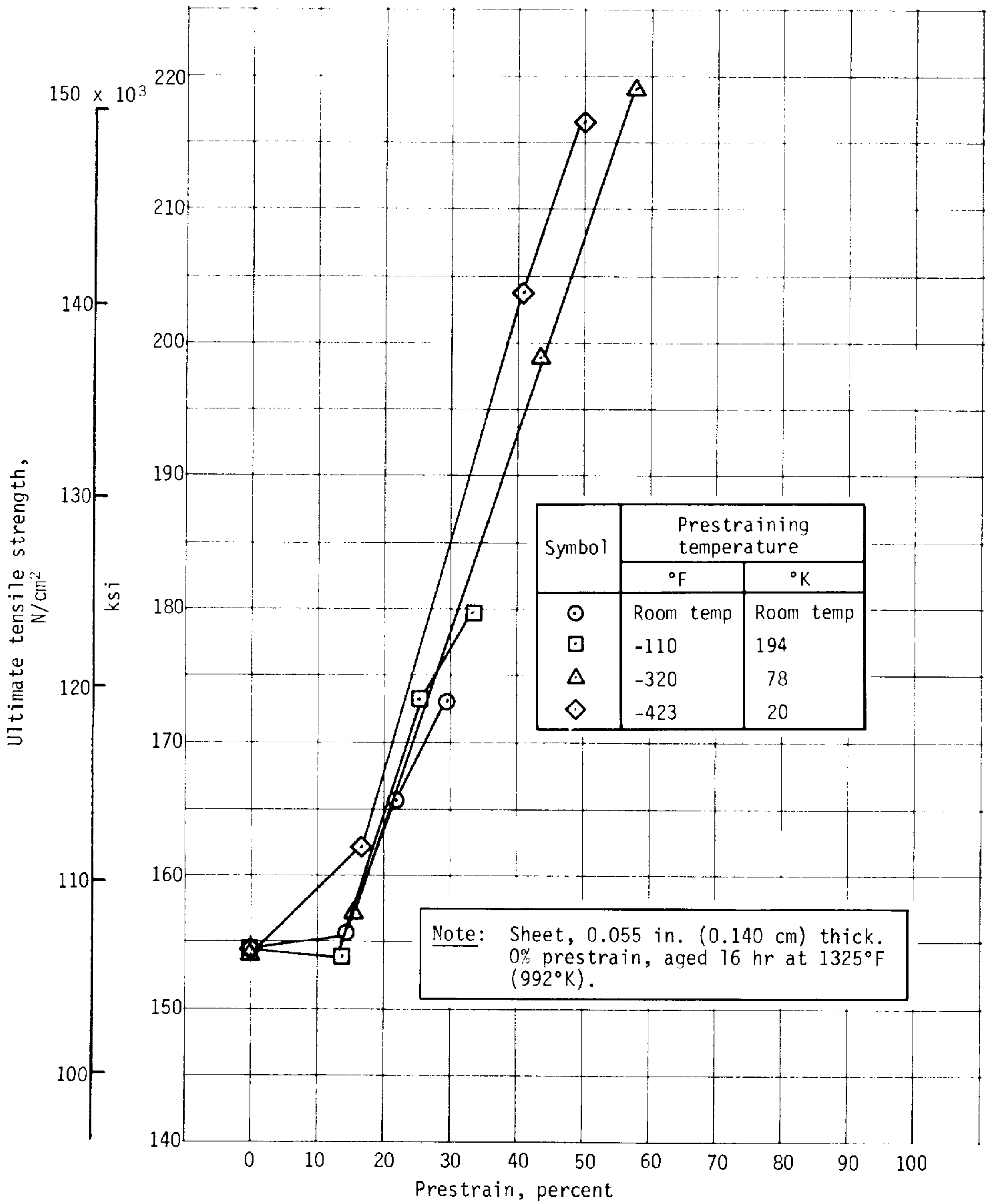


Figure 70.- Ultimate Tensile Strength of Prestrained A-286 Corrosion Resistant Steel, Aged 16 hr at 1150°F (894°K)

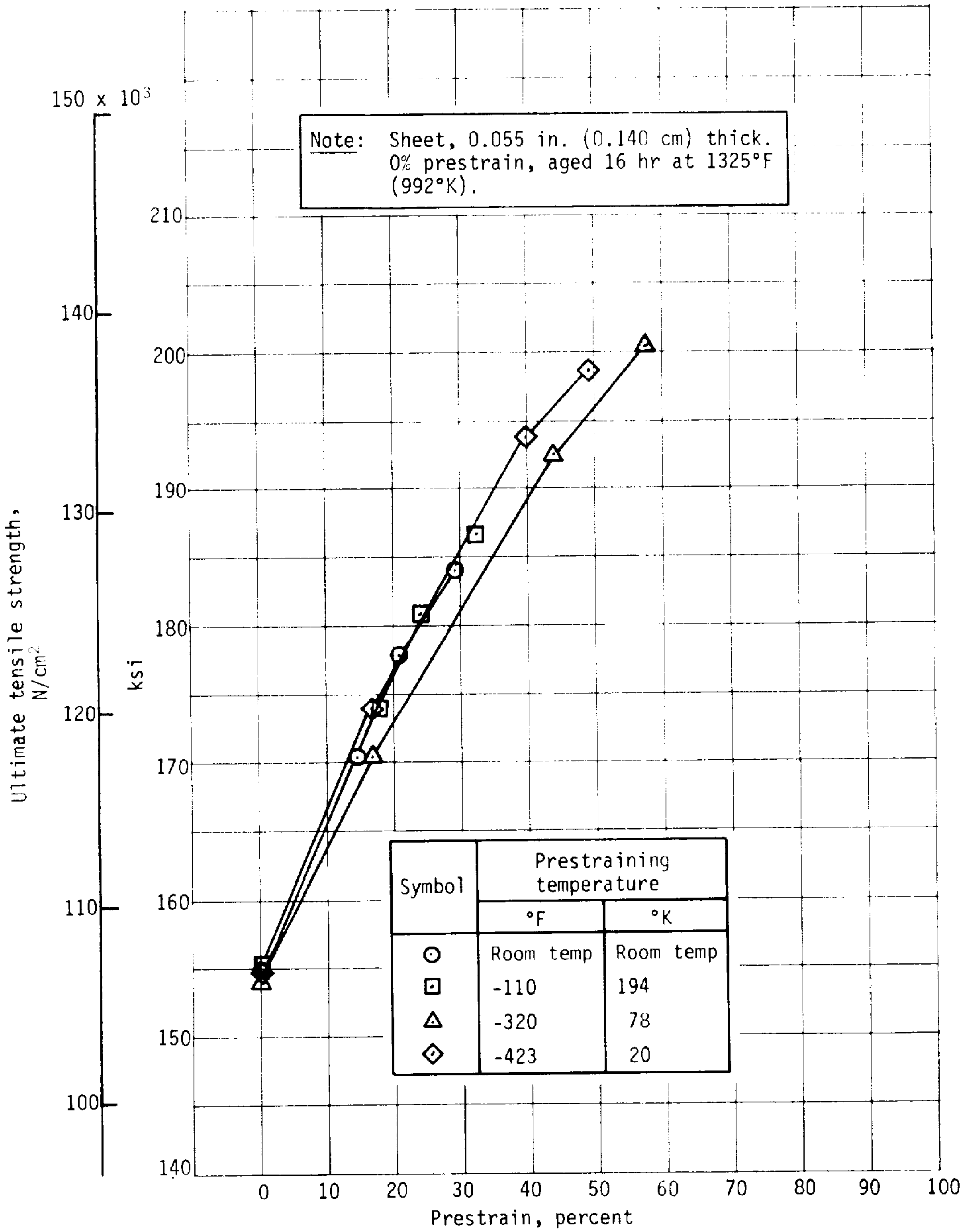


Figure 71.- Ultimate Tensile Strength of Prestrained A-286 Corrosion Resistant Steel, Aged 16 hr at 1250°F (951°K)

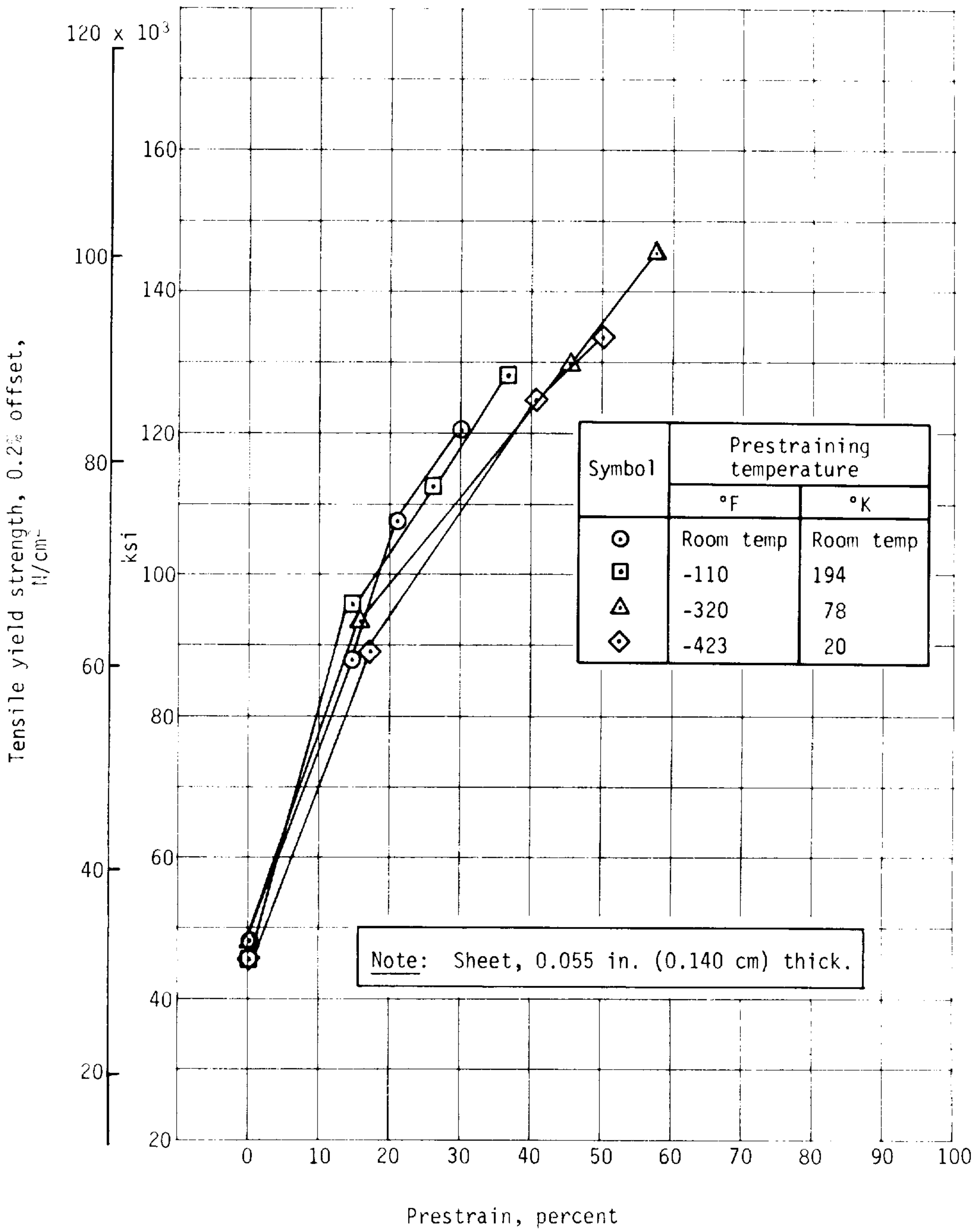


Figure 72.- Tensile Yield Strength of Prestrained A-286 Corrosion Resistant Steel

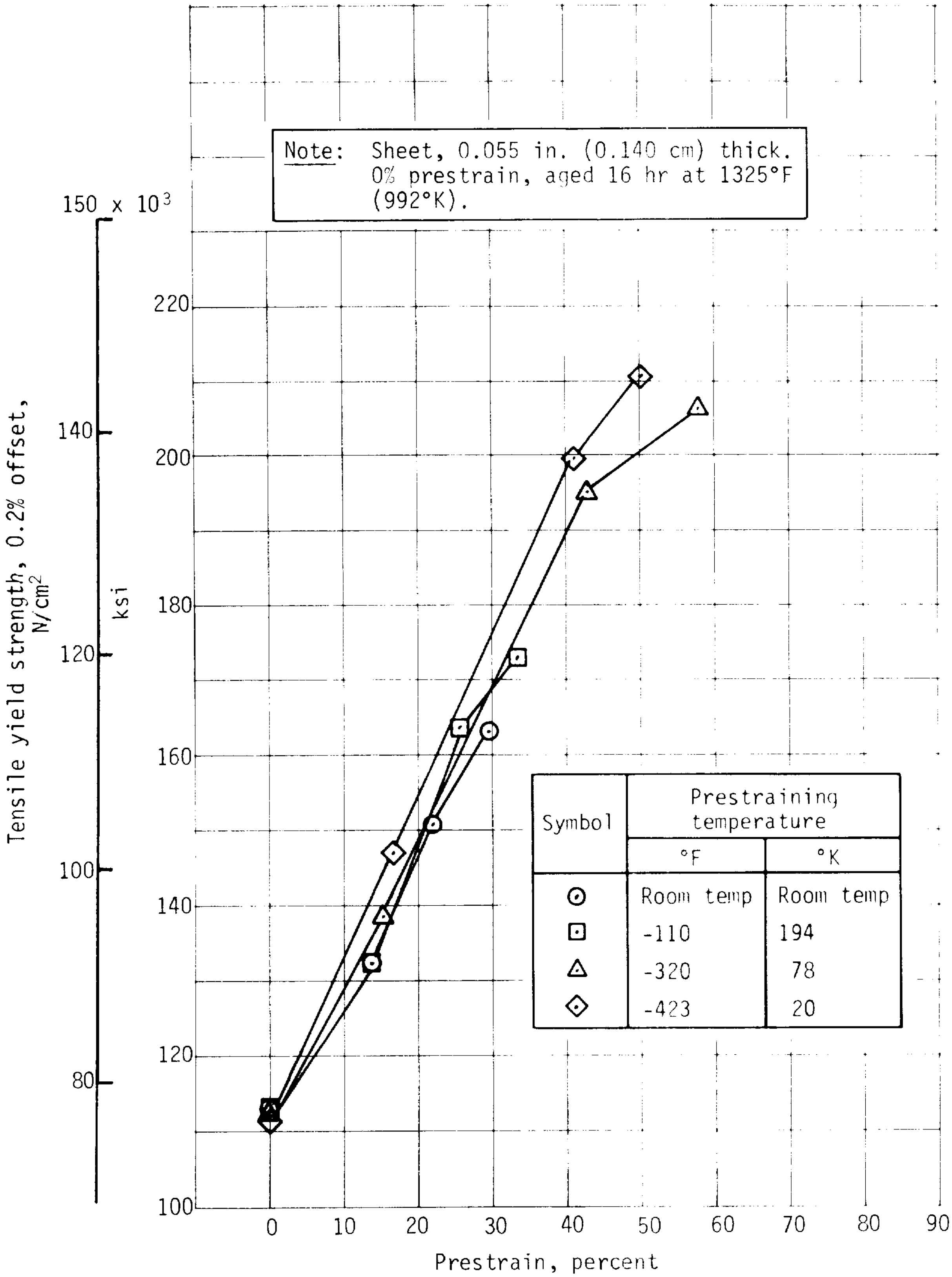


Figure 73.- Tensile Yield Strength of Prestrained A-286 Corrosion Resistant Steel, Aged 16 hr at 1150°F (894°K)

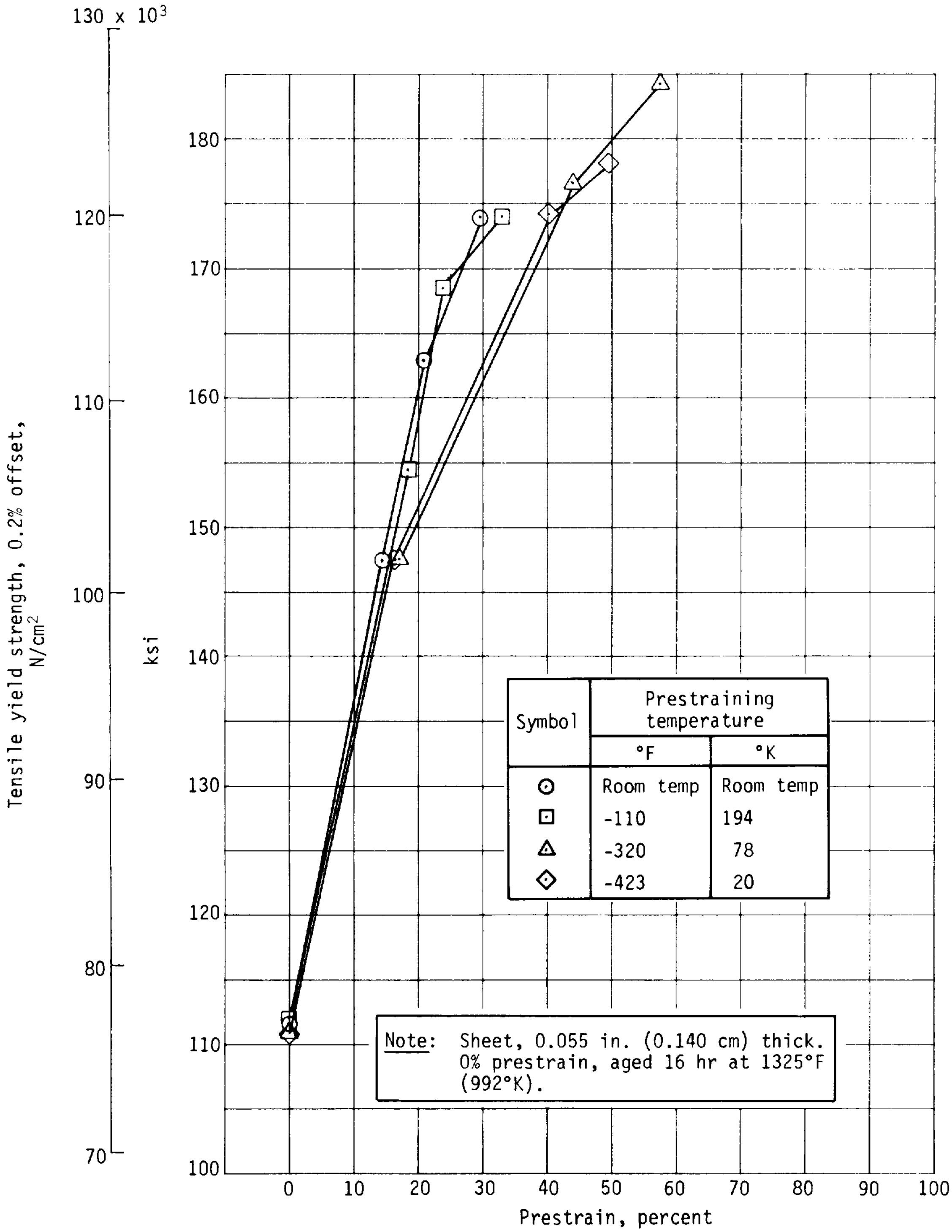


Figure 74.- Tensile Yield Strength of Prestrained A-286 Corrosion Resistant Steel, Aged 16 hr at 1250°F (951°K)

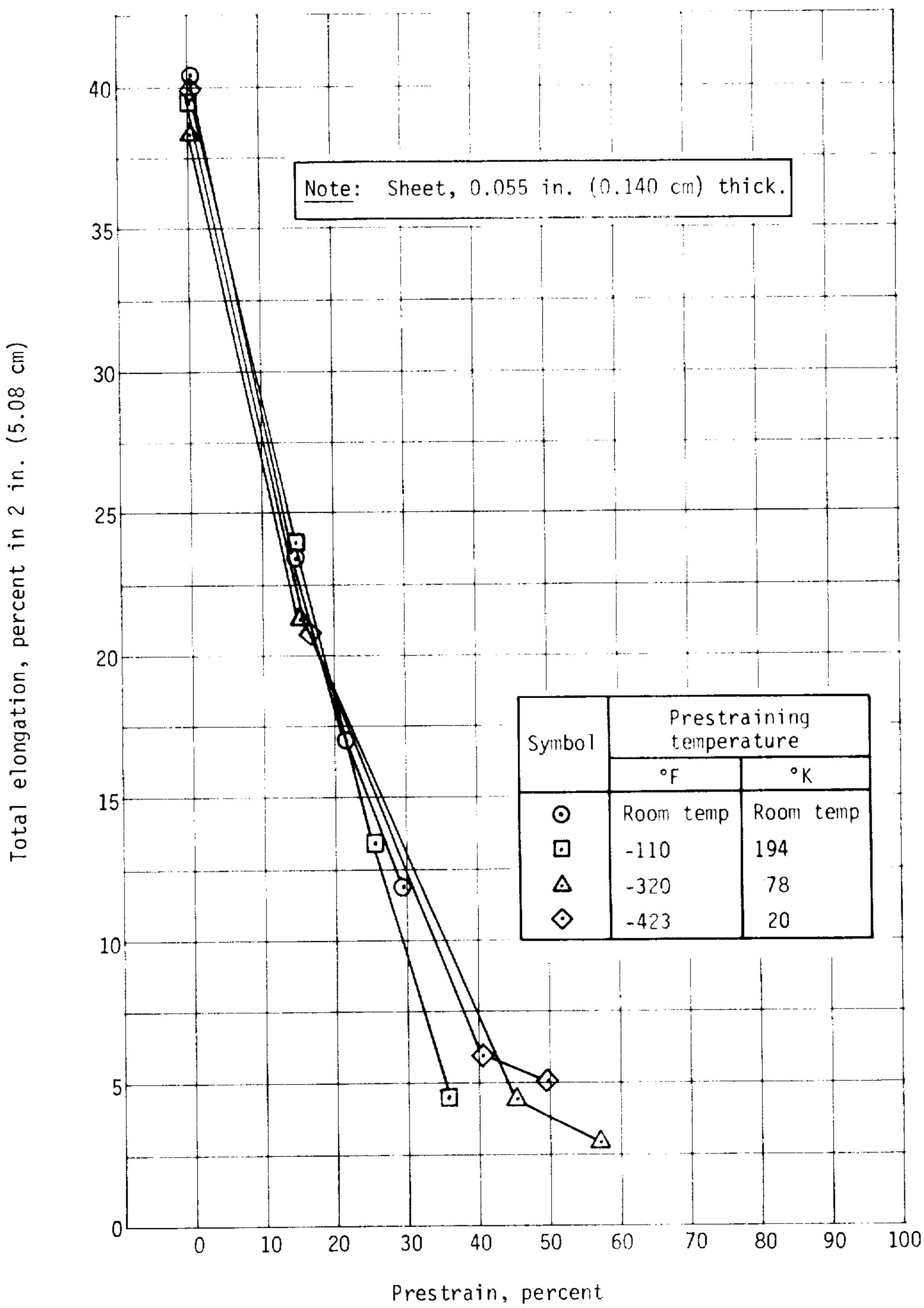


Figure 75.- Total Elongation of Prestrained A-286 Corrosion Resistant Steel

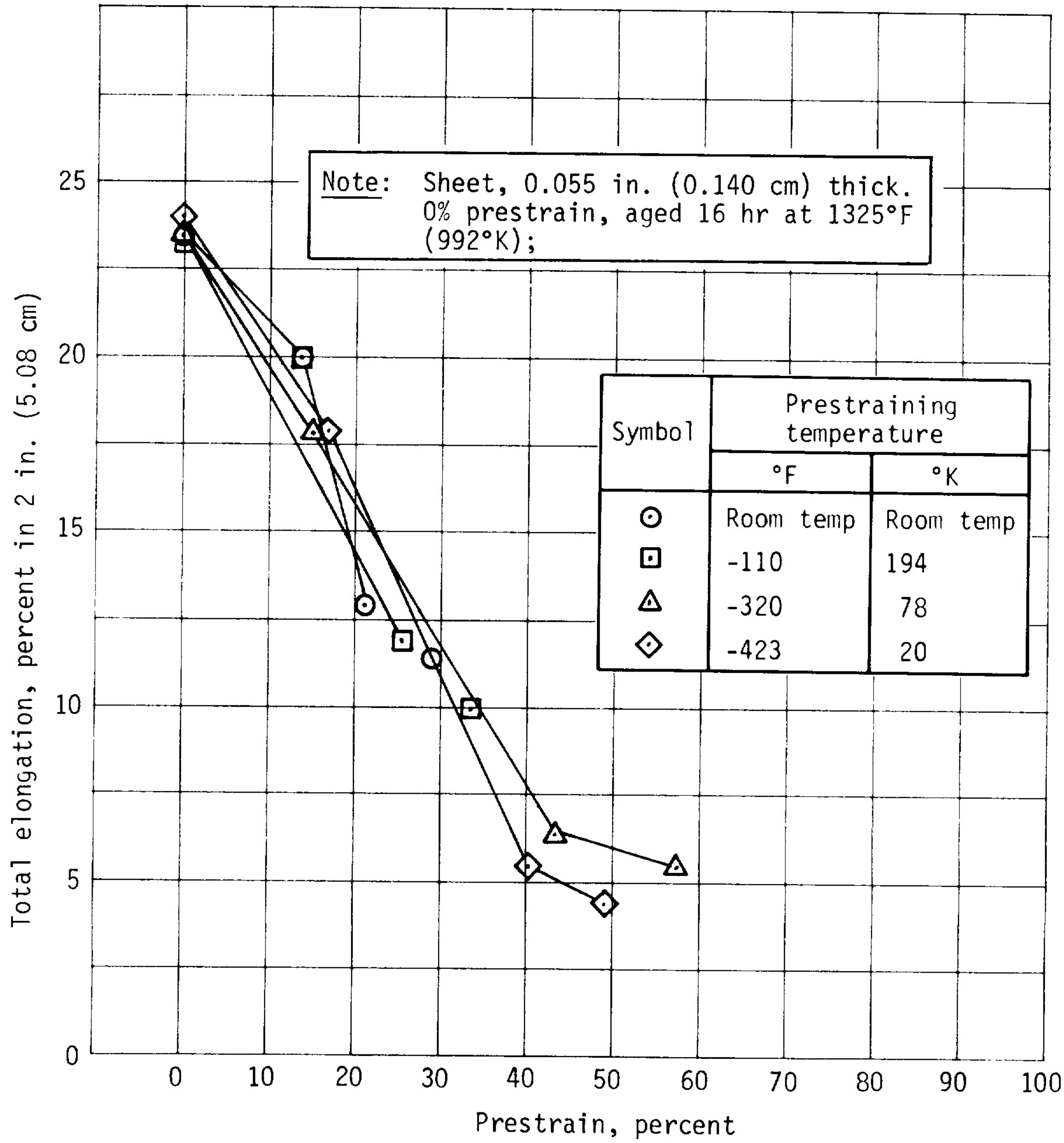


Figure 76.- Total Elongation of Prestrained A-286 Corrosion Resistant Steel, Aged 16 hr at 1150°F (894°K)

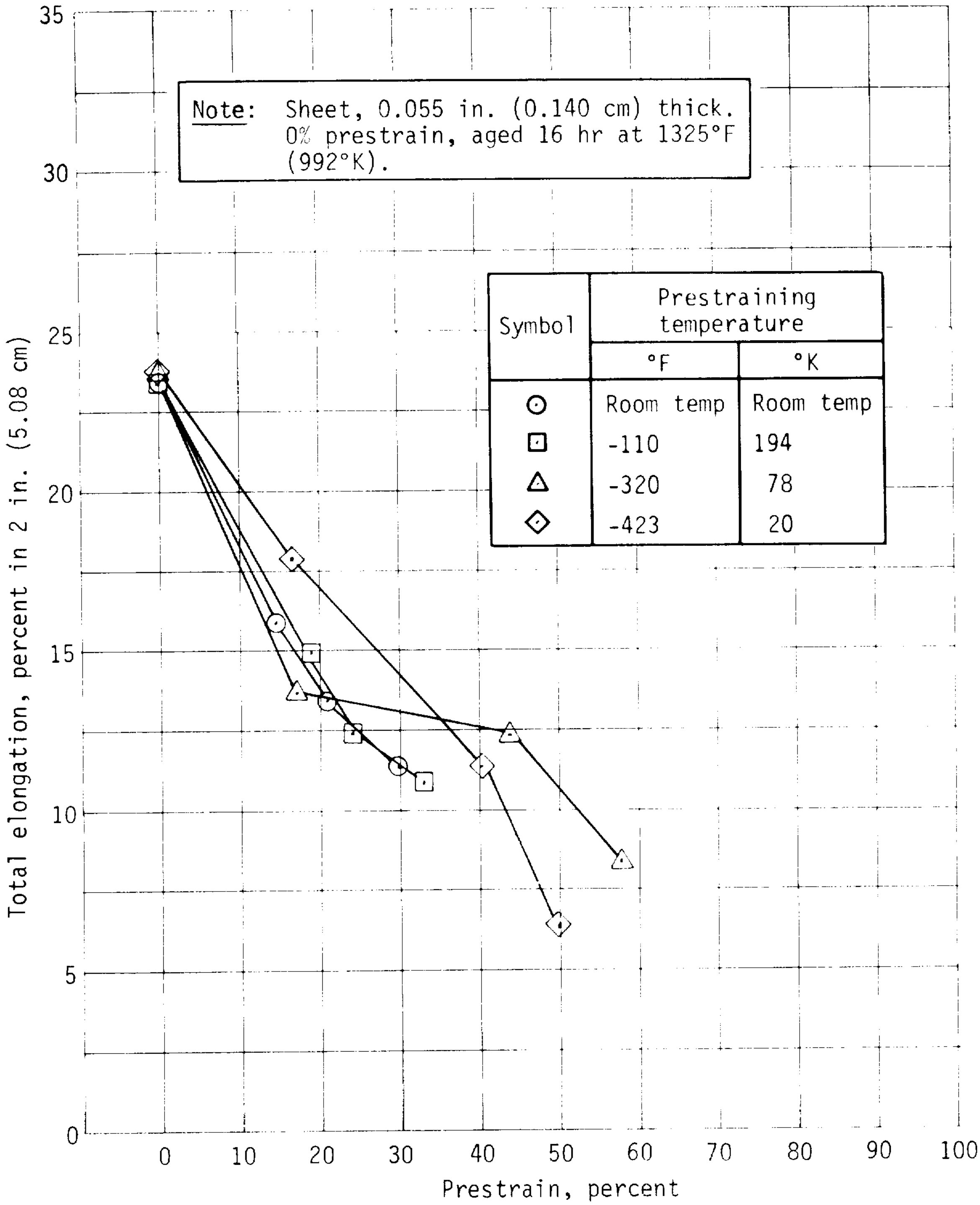
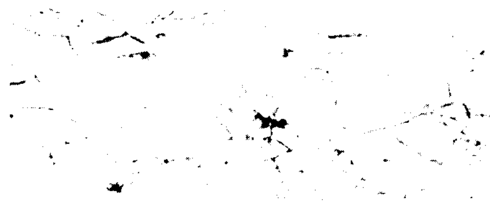
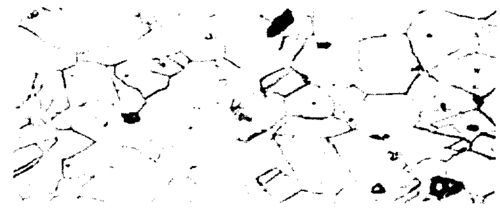


Figure 77.- Total Elongation of Prestrained A-286 Corrosion Resistant Steel, Aged 16 hr at 1250°F (951°K)

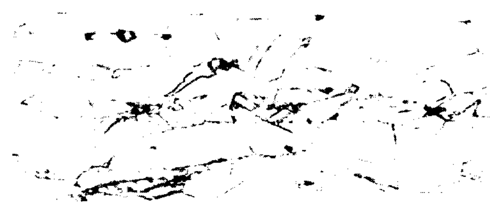


(a) Soak at Room Temperature, Unaged

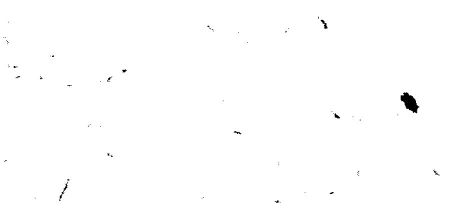


(b) Soak at Room Temperature, Aged 16 hr at 1325°F (992°K)

(c) 29% Strain at Room Temperature, Aged 16 hr at 1150°F (894°K)



(d) 33.5% Strain at -110°F (194°K), Aged 16 hr at 1150°F (894°K)



(e) Soak at -423°F (20°K), Unaged

(f) 49.5% Strain at -423°F (20°K), Aged 16 hr at 1150°F (894°K)

(g) 57.5% Strain at -320°F (78°K), Aged 16 hr at 1150°F (894°K)

<u>Note</u>: Aging has no marked effect on the appearance of the microstructure. Twinning becomes more evident with increasing strains.

Etch: HCL + HNO_3 + Acetic acid 250X

Figure 78.- Microstructure of A-286 Corrosion Resistant Steel

PH 14-8 Mo Corrosion Resistant Steel

A sheet of annealed PH 14-8 Mo corrosion resistant steel 0.070x36x120 in. (0.178x91x305 cm) was procured to North American Aviation materials specification MB0160-015. The chemical composition of the sheet material was:

Element	Percent by weight
C	0.038
Mn	0.10
P	0.003
S	0.004
Si	0.10
Cr	14.95
Ni	8.31
Mo	2.15
Aℓ	1.17
N	0.005
Fe	Balance

Density: 0.283 lb/cu in; 7.852 gm/cc

With one exception the PH 14-8 Mo specimens were prepared and processed according to normal procedures as described in Chapter III. The exception was that an additional machining operation was performed. The specimens were remachined after they had been strained. The width, and thus the area of the highly strained gage sections of the specimens, was reduced to prevent out-of-gage failures during subsequent tensile tests.

The PH 14-8 Mo specimens that had to be aged were aged at 900°F (756°K) for 1 hr and air cooled. These specimens were thoroughly cleaned and then coated with a protective lacquer before they were aged.

PH 14-8 Mo is a semi-austenitic precipitation hardening steel. In the solution treated or annealed condition the structure of this steel is austenitic. Transformation of austenite to martensite can be accomplished in either of two ways, by thermal treatment, or by cold working. The thermal treatment for PH 14-8 Mo requires that the material be heated to and held at 1700°F (1200°K) for 1 hr to condition it for transformation. Then, it must be cooled to -100°F (200°K) and held at that temperature for 8 hr to transform the austenite to martensite. An aging treatment, at either 950°F (782°K) or 1050°F (840°K) follows the transformation treatment. The conditions after aging are identified as SRH 950 and SRH 1050, respectively. The cold-work treatment is normally a mill treatment. Annealed PH 14-8 Mo is transformed to martensite by heavy cold reduction. It is then aged at 900°F (755°K) for 1 hr. The condition after aging is CH 900. For this program the CH treatment was selected because by following this procedure the material could be strained in the annealed (austenitic) condition.

The results of the tests conducted on the PH 14-8 Mo specimens are given in figures 79 through 84, and are listed in tables 22 and 23 of the Appendix. Photomicrographs of the microstructure of this material after various treatments are shown in figure 85.

PH 14-8 Mo had less uniform strain capability at the cryogenic temperatures than at room temperature, specifically, 21.0% at room temperature, 13.0% at -110°F (194°K), 18.5% at -320°F (78°K), and 15.0% at -423°F (20°K). Exposure to the cryogenic temperatures did not change the room temperature tensile properties of this steel. However, straining PH 14-8 Mo at cryogenic temperatures, particularly at -320°F (78°K), proved to be a much more effective strengthening treatment than room temperature straining. The room temperature tensile properties of PH 14-8 Mo, after aging, are listed in the following table. The specimens were aged 1 hr at 900°F (755°K) after exposure to temperature or straining at temperature.

Straining temperature		Amount strained	Ultimate tensile strength,		Tensile yield strength, 0.2% offset		Elongation, percent in 2 in. (5.08 cm)
°F	°K	%	psi	N/cm^2	psi	N/cm^2	
Room Temp	Room Temp	0	127 800	88 100	54 700	37 700	28.0
		5.5	139 900	96 500	87 400	60 300	27.5
		13.5	199 700	137 700	197 600	136 200	10.0
		17.5	231 400	159 600	231 100	159 300	4.0
-110	194	0	129 400	89 200	55 400	38 200	28.0
		5.5	214 800	148 100	195 300	134 700	7.0
		7.0	249 700	172 200	247 500	170 700	7.0
		10.0	271 700	187 300	271 700	187 300	6.5
-320	78	0	130 300	89 800	54 000	37 200	27.5
		6.5	250 500	172 700	181 800	125 400	6.5
		10.5	305 400	210 600	298 200	206 000	6.0
		14.5	329 400	227 100	326 800	225 300	5.0
-423	20	0	130 400	89 900	54 100	37 300	27.5
		4.5	164 900	113 700	76 600	52 800	8.0
		7.8	260 000	179 300	217 900	150 200	10.0
		10.2	284 300	196 000	261 200	180 100	7.0

On the basis of the test results it can be hypothesized that straining at cryogenic temperatures enhances the austenite to martensite transformation and may increase the aging response of PH 14-8 Mo. Cryostraining is definitely a process by which the room temperature tensile strength of PH 14-8 Mo can be increased. However, there are indications that the toughness of this alloy is affected when it has been highly strained. Further investigation of this alloy to determine the effects of cryostraining on its toughness, corrosion resistance, and other properties is recommended.

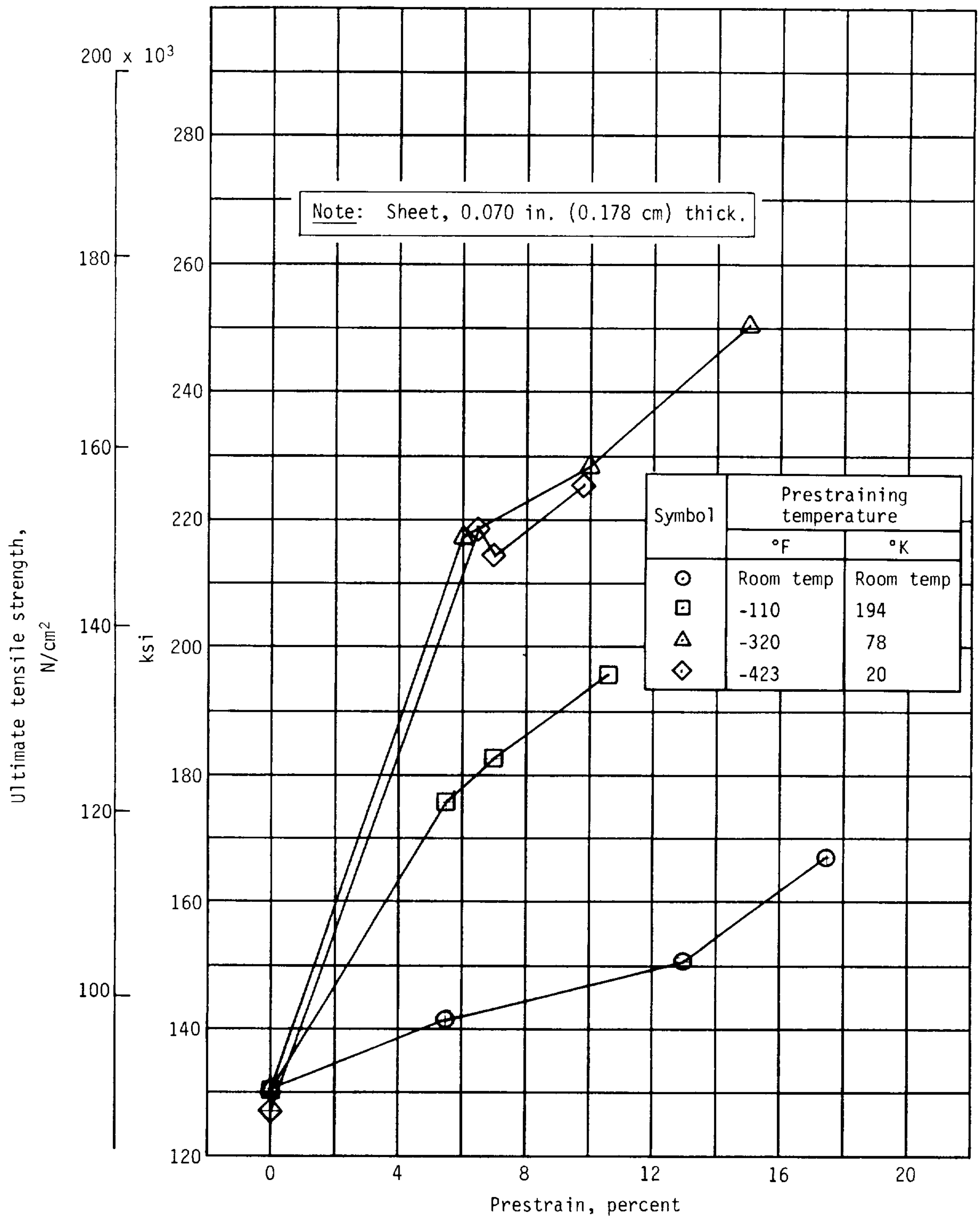


Figure 79.- Ultimate Tensile Strength of Prestrained PH 14-8 Mo Steel

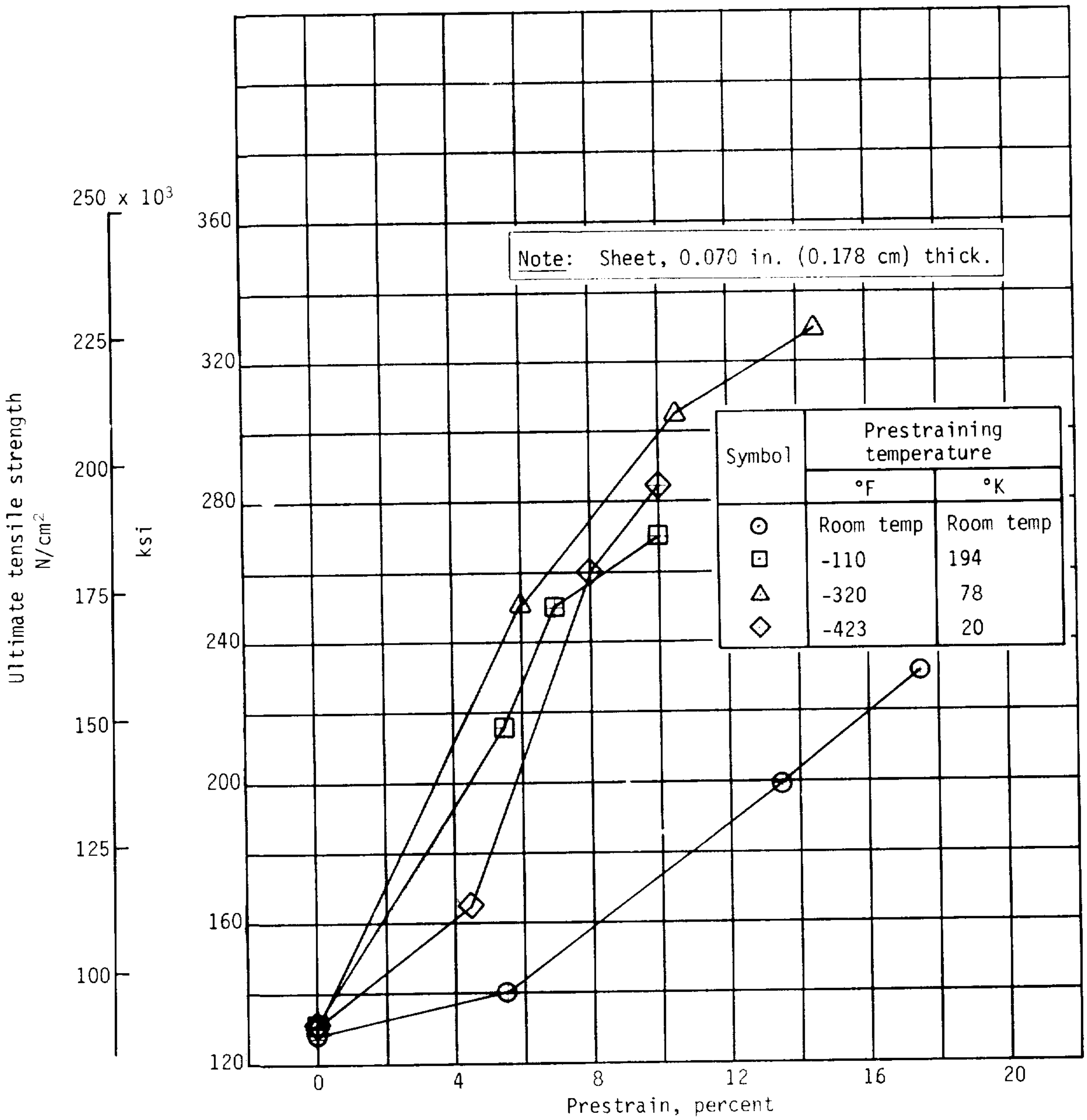


Figure 80.- Ultimate Tensile Strength of Prestrained PH 14-8 Mo Steel, Aged 1 hr at 900°F (756°K)

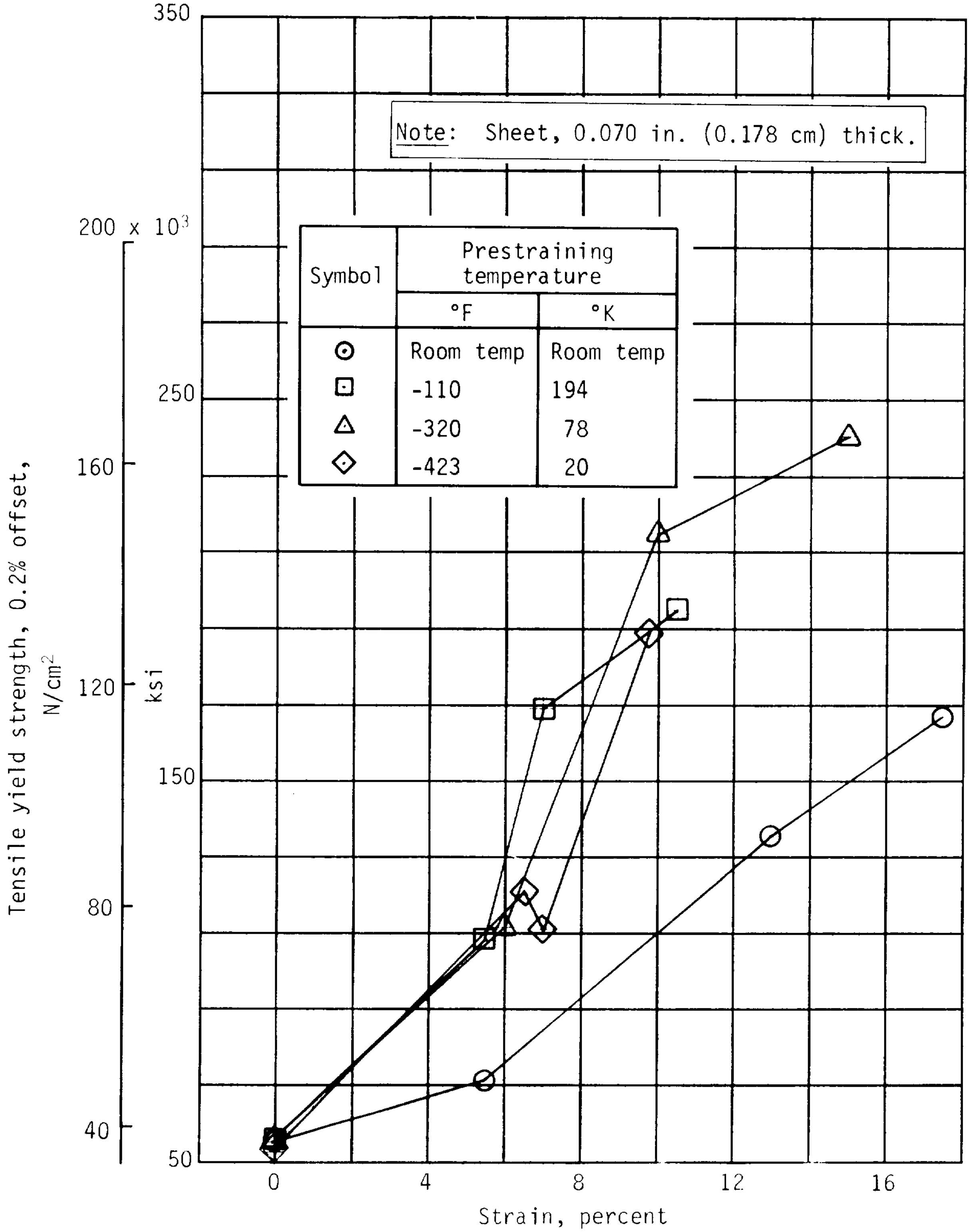


Figure 81.- Tensile Yield Strength of Prestrained PH 14-8 Mo Steel

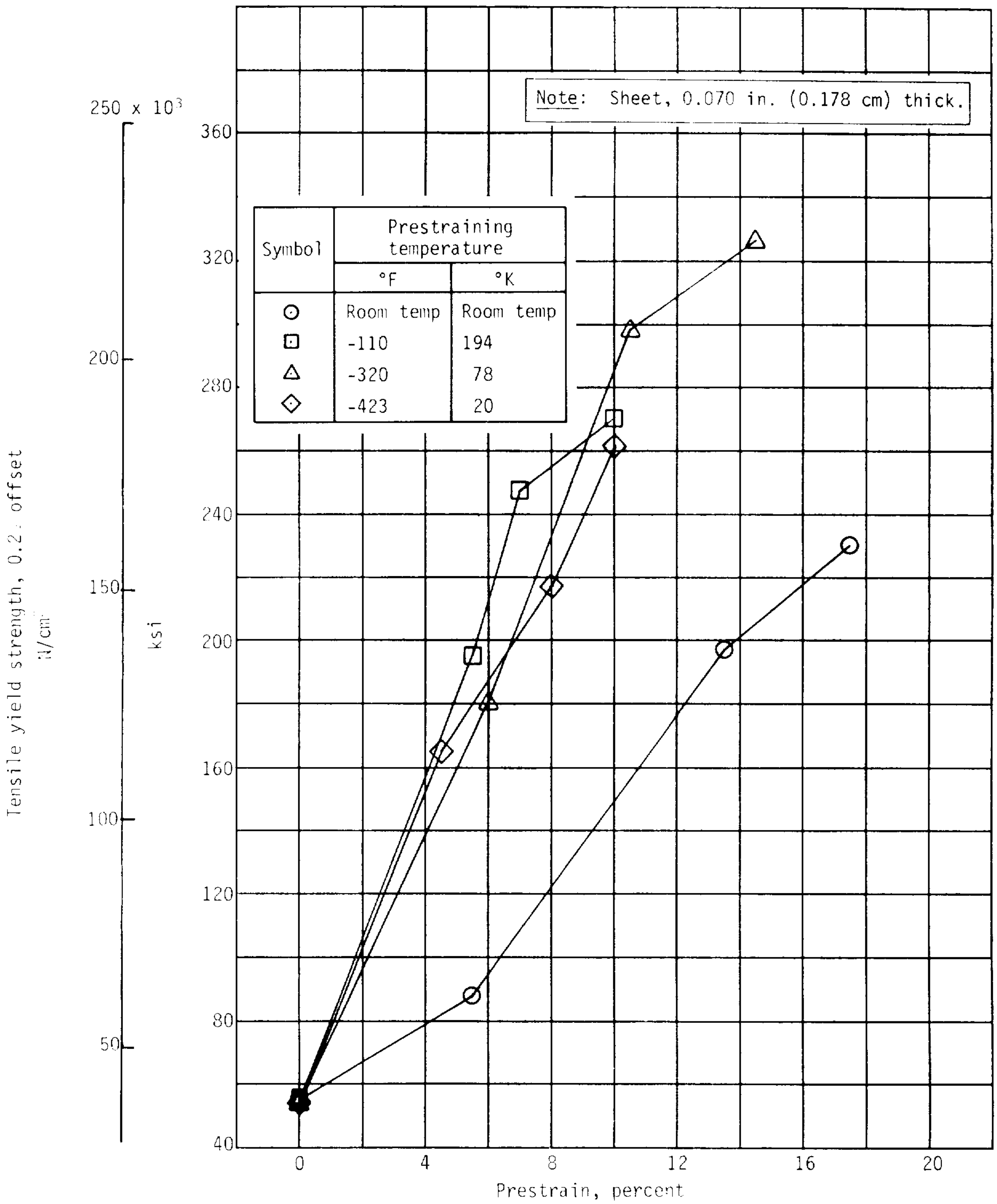


Figure 82.- Tensile Yield Strength of Prestrained PH 14-8 Mo Steel, Aged 1 hr at 900°F (756°K)

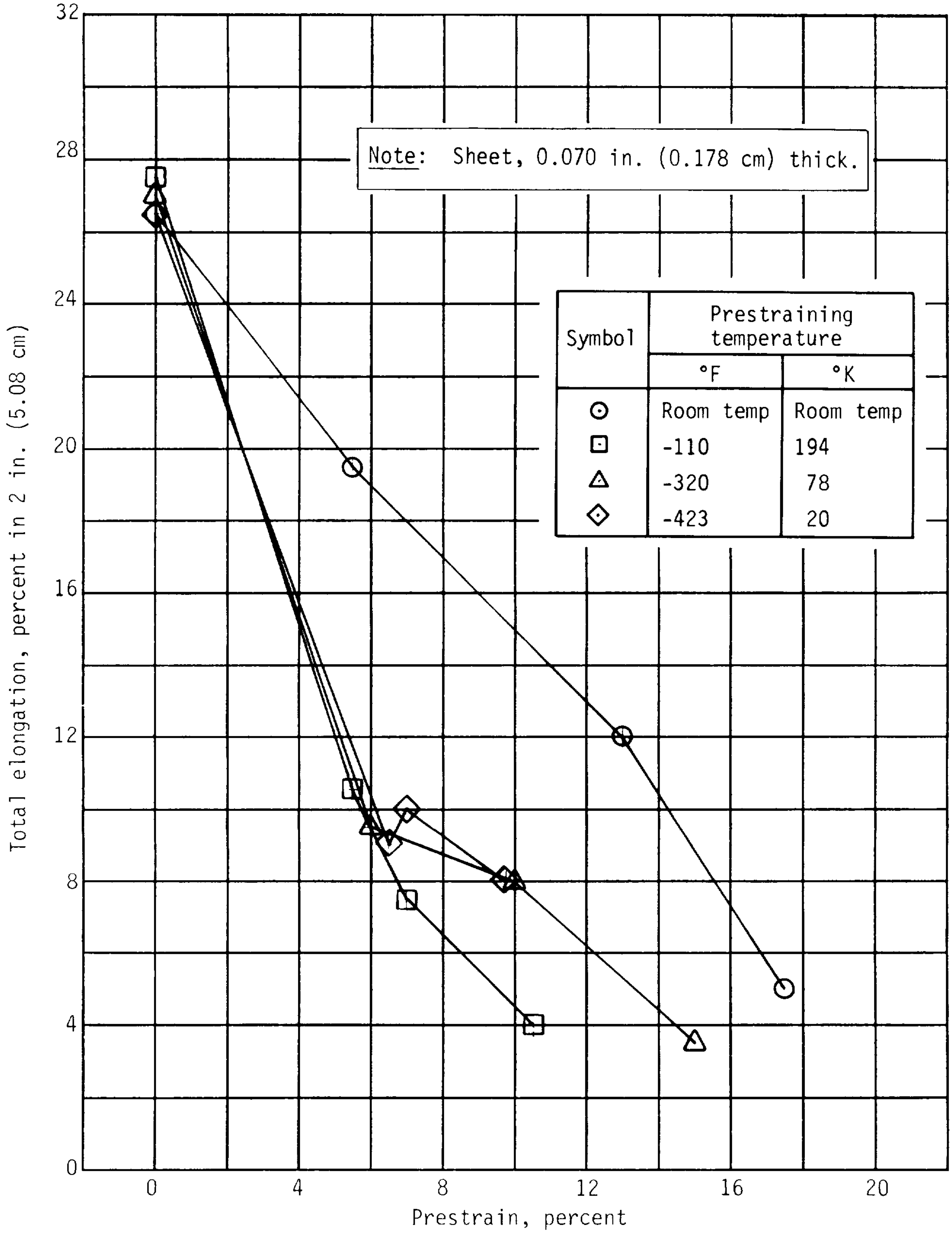


Figure 83.- Total Elongation of Prestrained PH 14-8 Mo Steel

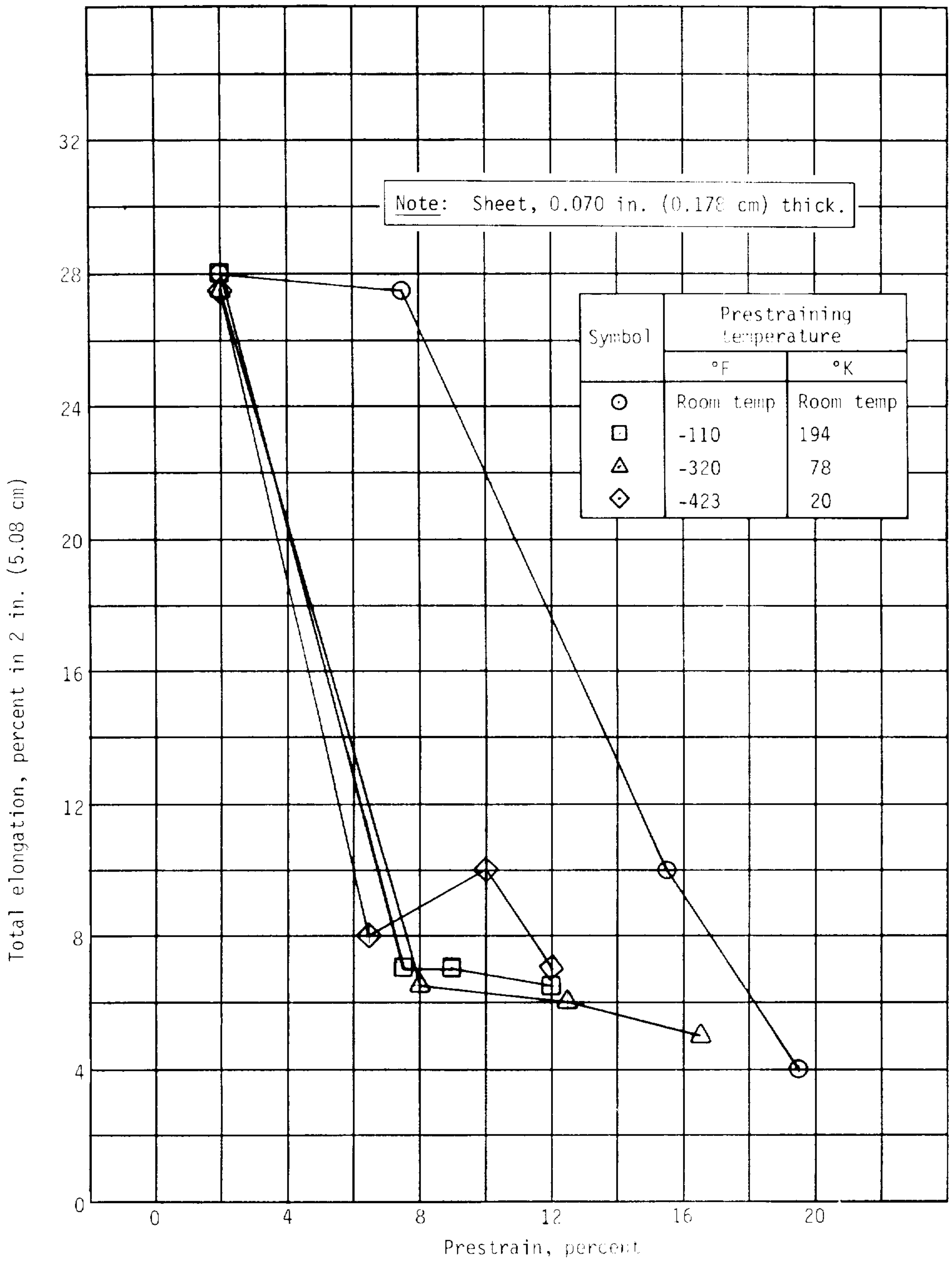


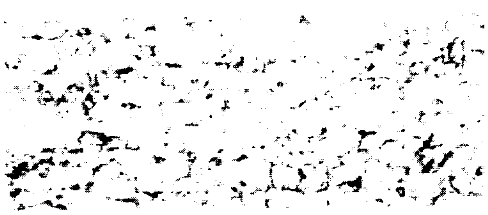
Figure 84.- Total Elongation of Prestrained PH 14-8 Mo Steel, Aged 1 hr at 900°F (756°K)

(a) Soaked at Room Temperature, Unaged

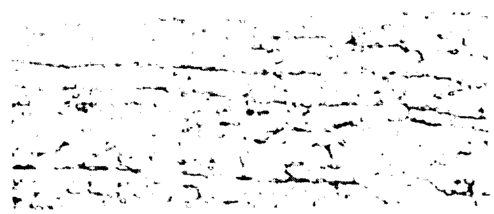
(b) Soaked at Room Temperature, Aged 1 hr at 900°F (756°K)

(c) Soaked at -423°F (20°K), Unaged

(d) Soaked at -423°F (20°K) Aged 1 hr at 900°F (756°K)



(e) 14.5% Strain at -320,F (78°K), Unaged



(f) 12.0% Strain at -423°F (20°K), Aged 1 hr at 900°F (756°K)

Note: Soaking at different temperatures did not change the microstructure of either the aged or the unaged material. Straining induced a partial transformation at austenite to martensite.

Electroetch: HCL + Methanol

750X

Figure 85.- Microstructure of PH 14-8 Mo Corrosion Resistant Steel

TRIP Steel

This material was procured in the form of strip, 0.110 in. thick x 6½ in. (0.279x17 cm) wide. A total of 36 ft (1097 cm) of the strip stock was procured to commercial requirements. The chemical composition of the material was:

Element	Percent by width
C	0.30
Mn	2.03
Si	2.03
Cr	9.35
Ni	8.30
Mo	3.60
Fe	Balance

The designation TRIP is an acronym for TRansformation Induced Plasticity. This designation has been applied to a new class of high-strength, ductile steel alloys. The initial structure of these steels is highly deformed austenite, that will transform to martensite during straining. The strip material used in the program was procured in the "TRIP processed" condition, a mill condition.

TRIP steel proved to be an interesting material that was very difficult to work with. It was difficult to shear, machine, strain, and test.

A number of special procedures were required for this steel:

1) Only pin-loaded specimens of the type shown in figure 3(a) were used, grip loading was not practical;

2) The as-rolled surface of the strip material proved to be unsuitable for straining and testing. Consequently, the gage portion of all the TRIP steel specimens was ground. An equal amount of material, 0.100 in. (0.025 cm) minimum, was removed from both sides, reducing the thickness of the gage section to approximately 0.090 in. (0.229) cm). After grinding, the specimens were electropolished to remove an additional 0.003 to 0.005 in. (0.008 to 0.013 cm) of stock from all surfaces;

3) The TRIP steel strained plastically in a progressive manner. Usually plastic strain began at one end of a gage section and slowly progressed the entire length of the gage. Progressive plastic straining would then begin again, usually at the same location that the initial plastic strain had occurred, but most of the time fracture would occur before the entire gage had strained a second time. Straining could be followed by observing the changing width and thickness of the specimen at the location where strain was occurring at any given instant. To illustrate this phenomena, several specimens that were being tested at room temperature fractured near midgage before the entire gage had strained plastically. Because the specimens had been photogridded with a 0.100 in. (0.254 cm) square

grid pattern it was possible to measure strain on both sides of the fracture. On one side of the fracture a uniform strain of from 15 to 20% was measured while on the other side of the fracture the strain was too small to measure. Because of this progressive mode of straining, the TRIP steel specimens were strained not to three strain levels at each temperature, as stated in Chapter III, but to only one. The specimens were strained until the entire gage section had strained once, to provide a more or less uniform plastic strain throughout the gage, and then the load was released;

4) On all specimens tested at -423°F (20°K), 0% uniform plastic strain was measured. Consequently, no TRIP steel specimens were strained at -423°F (20°K).

The results of the tests conducted on the TRIP steel specimens are given in figures 86 through 91, and listed in tables 24 and 25 of the Appendix. Photomicrographs of this material after various treatments are shown in figure 92.

The TRIP steels have been designed to transform from austenite to martensite when they are strained. Because straining is more easily accomplished at room temperature than at cryogenic temperatures there is no advantage to be gained from cryostraining TRIP steel.

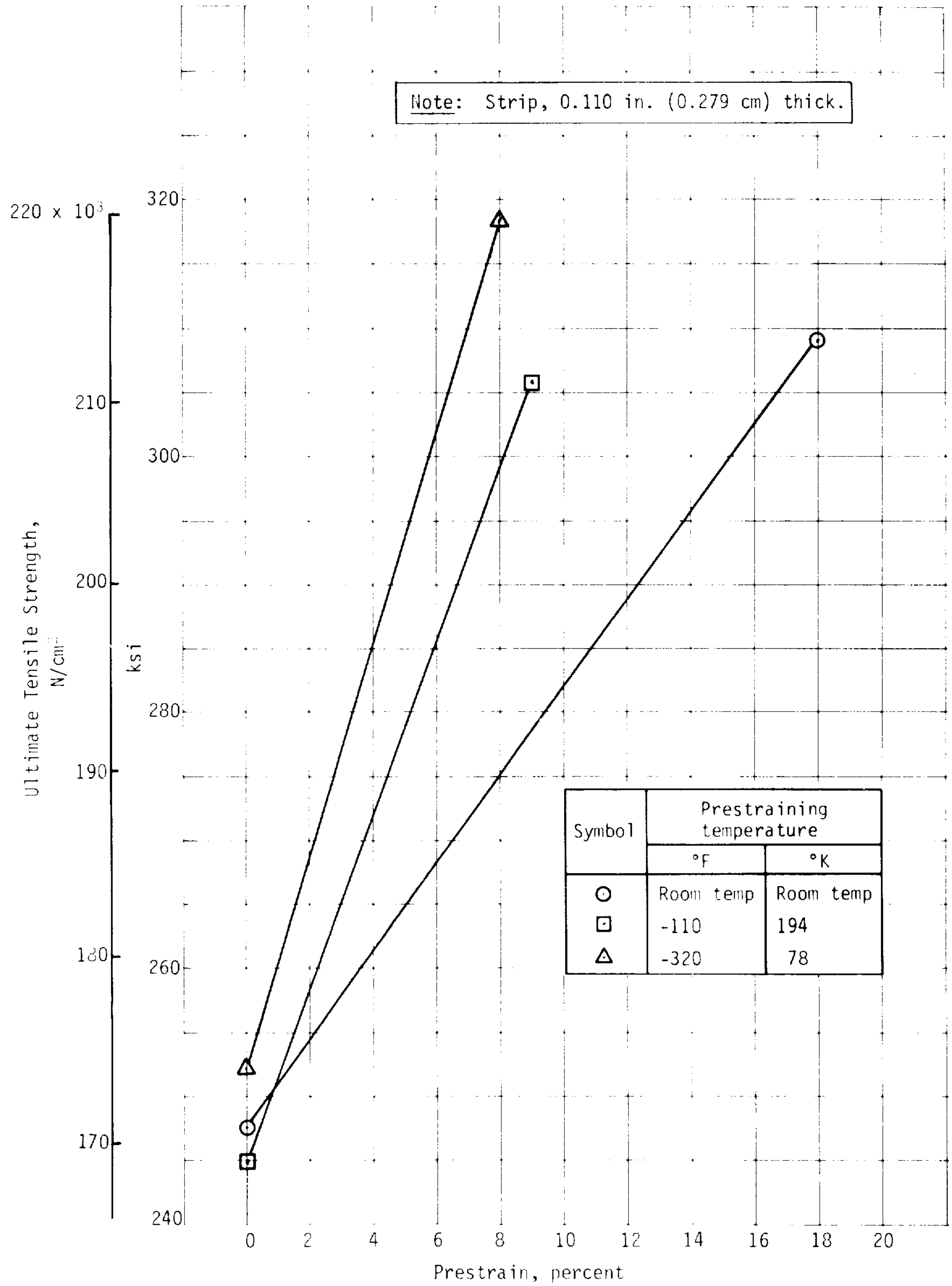


Figure 86.- Ultimate Tensile Strength of Prestrained TRIP Steel

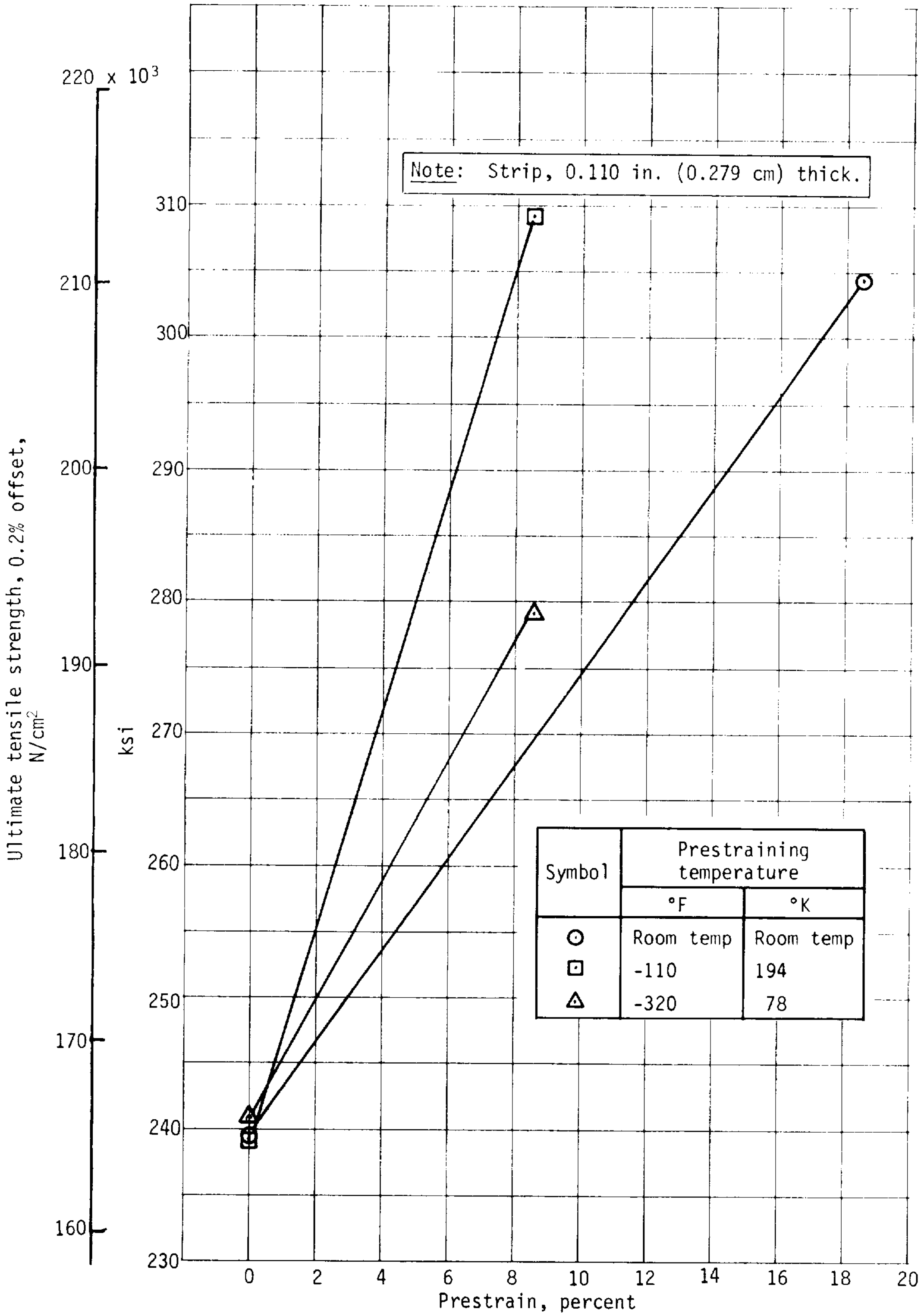


Figure 87.- Ultimate Tensile Strength of Prestrained TRIP Steel, Aged 0.5 hr at 750°F (673°K)

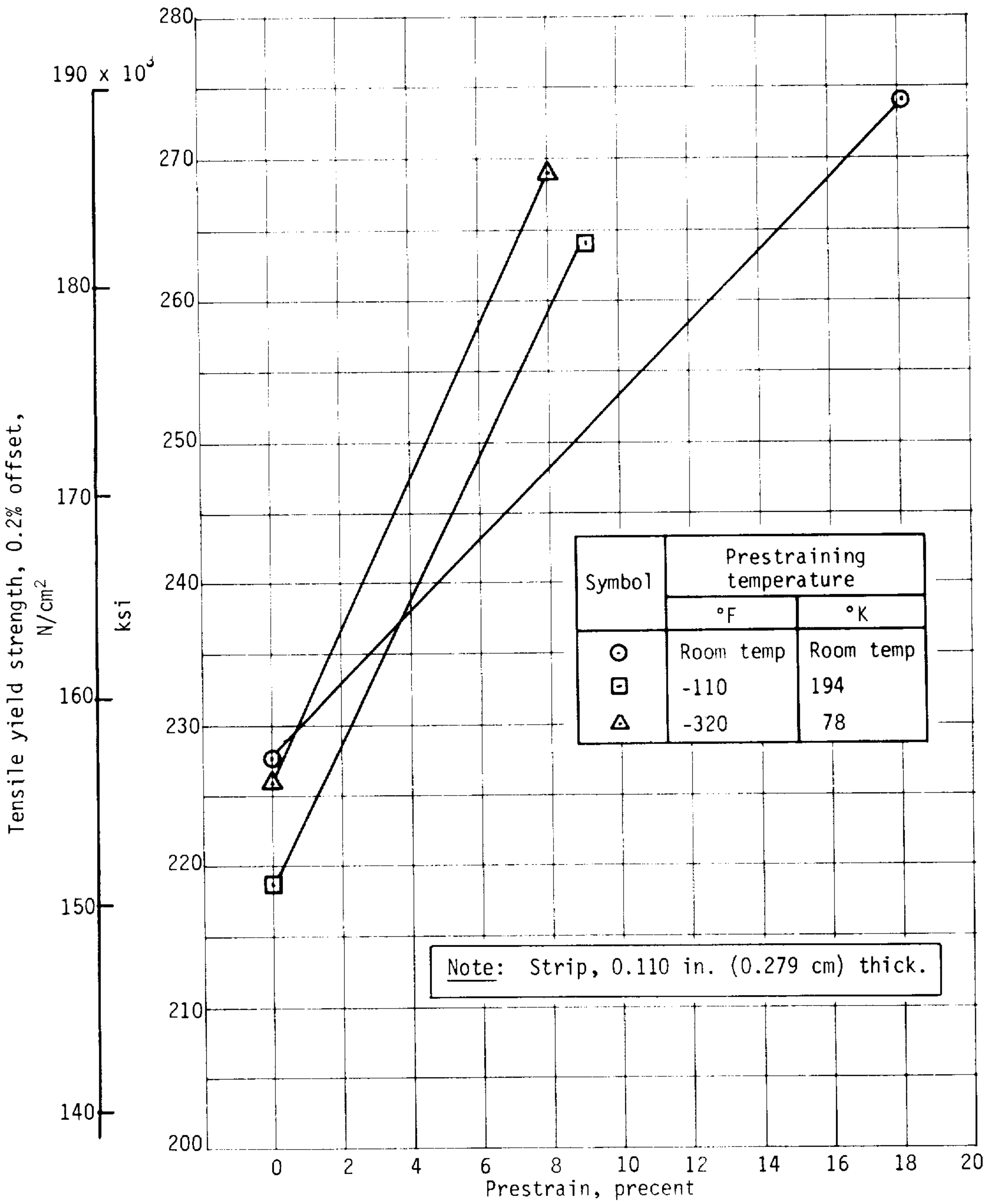


Figure 88.- Tensile Yield Strength of Prestrained TRIP Steel

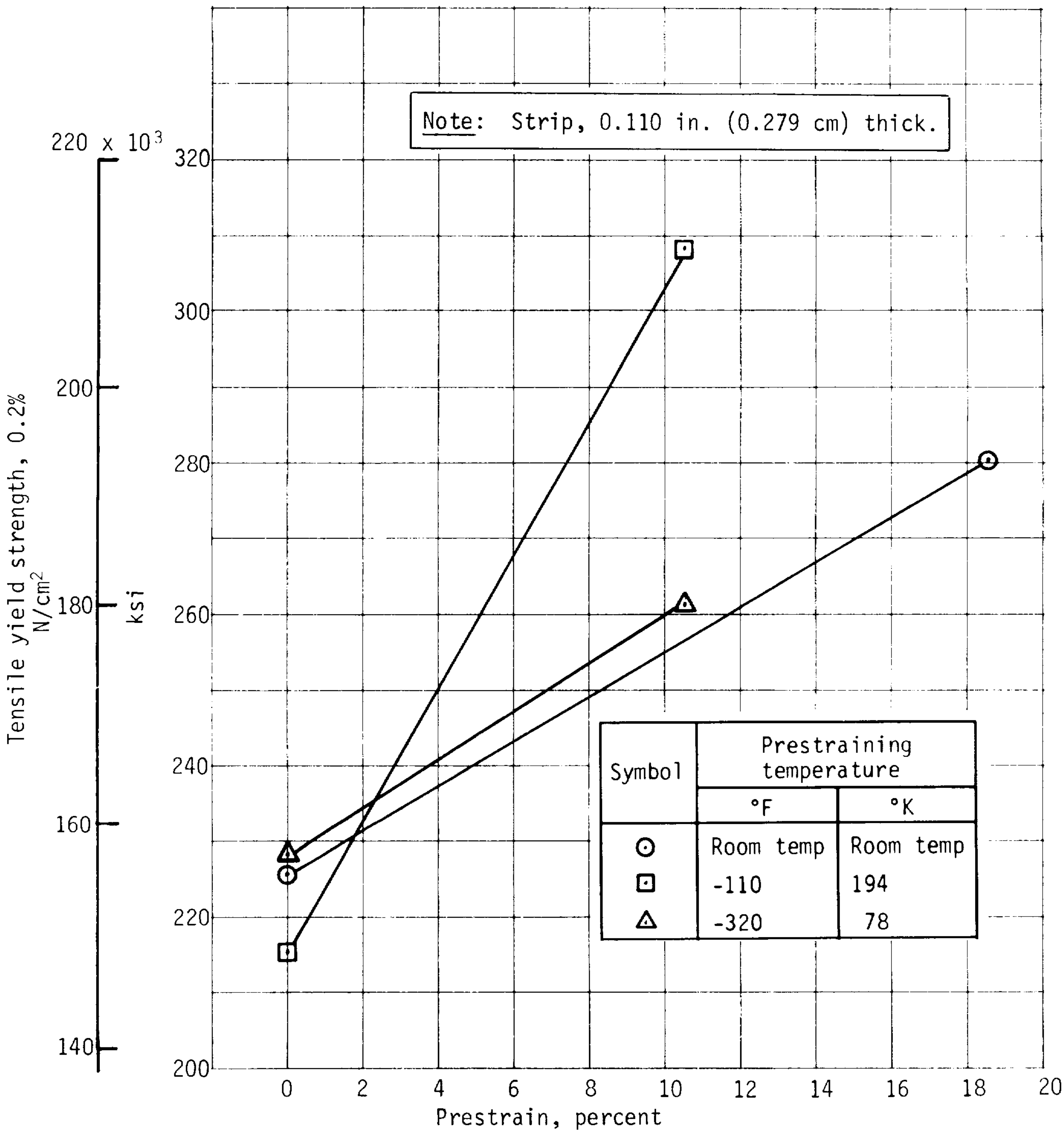


Figure 89.- Tensile Yield Strength of Prestrained TRIP Steel, Aged 0.5 hr at 750°F (673°K)

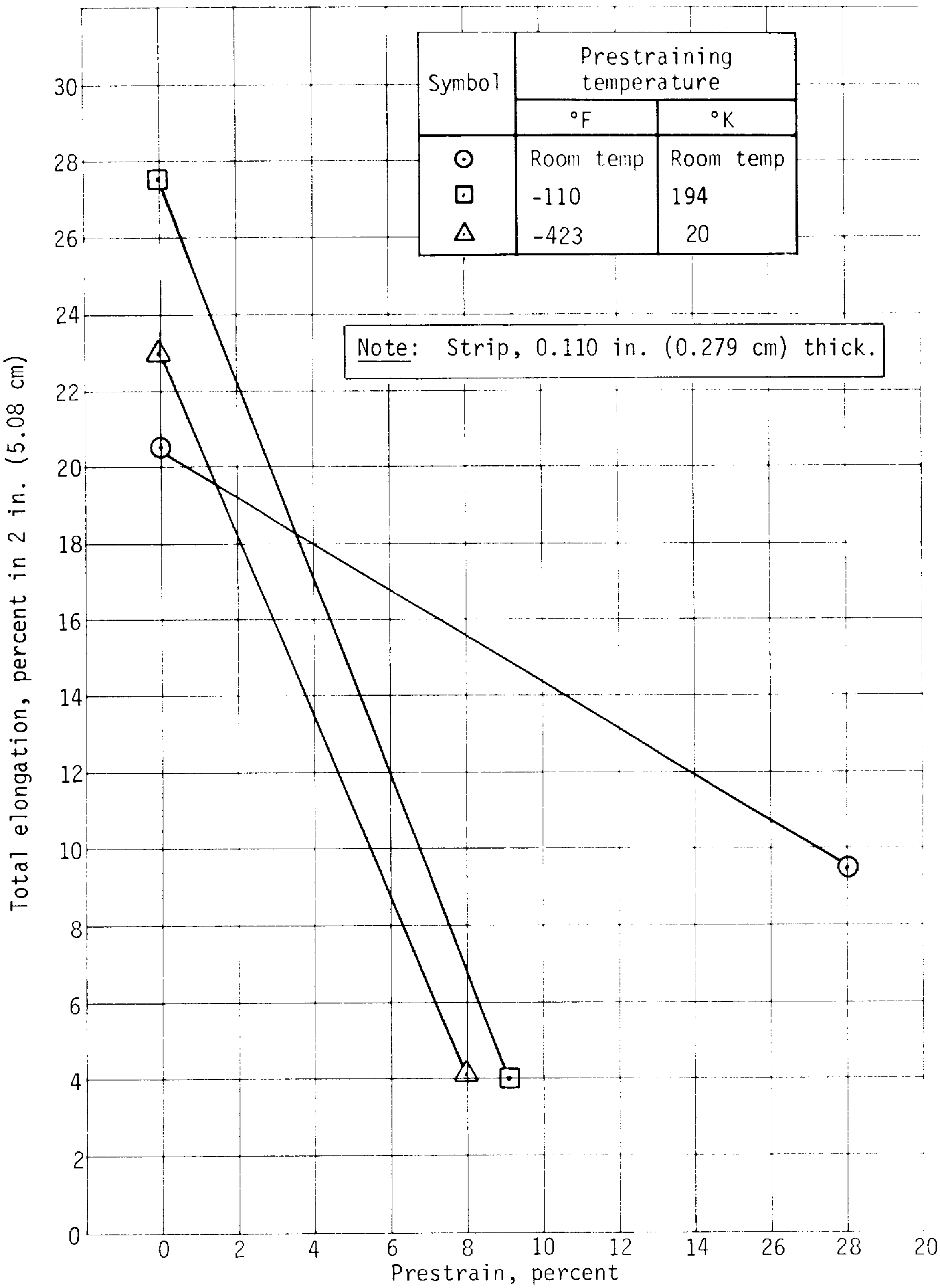


Figure 90.- Total Elongation of Prestrained TRIP Steel

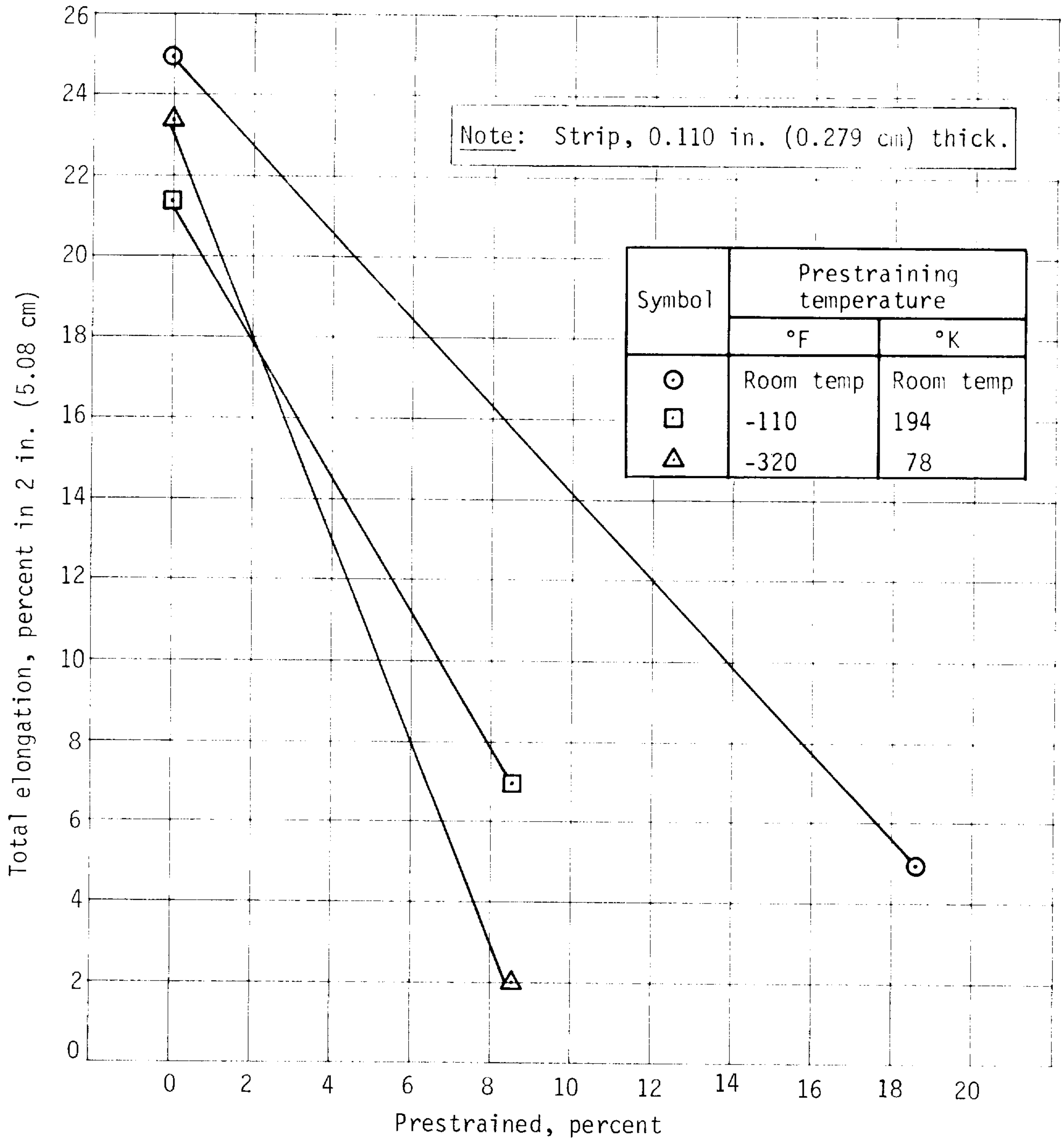
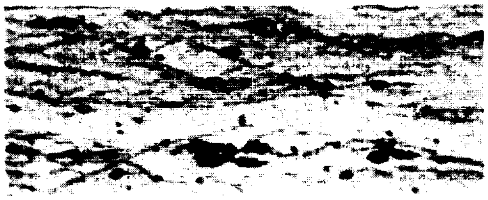
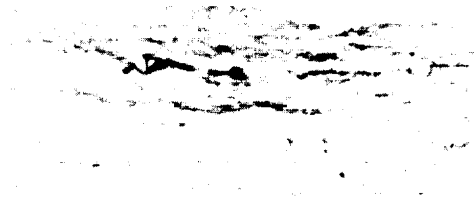


Figure 91.- Total Elongation of Prestrained TRIP Steel, Aged 0.5 hr at 750°F (673°K)



(a) Soaked at Room Temperature, Aged 0.5 hr at 750°F (673°K)



(b) 8.0% Strain at -320°F (78°K), Aged 0.5 hr at 750°F (673°K)

Note: The microstructure of this material was so severely affected by the room temperature tensile test to failure that the results of pretest treatments could not be evaluated.

Figure 92.- Microstructure of TRIP Steel

21-6-9 Corrosion Resistant Steel

One sheet of 21-6-9 corrosion resistant steel was obtained and used in the program. The sheet, which was procured to commercial requirements measured, 0.062x48x48 in. (0.157x122x122 cm). A chemical analysis showed that the composition of the sheet was:

Element	Percent of weight
C	0.01
Mn	9.20
Si	0.93
Cr	20.80
Ni	6.80
N	0.36
Ti	0.08
Cb	0.18
Mo	0.25
Fe	Balance

Density: 0.283 lb/cu in.; 782 gm/cc

The 21-6-9 steel is an austenitic stainless steel that is strengthened by strain hardening but not by thermal treatment. It has, in the annealed condition, about twice the yield strength of conventional 18-8 stainless steels. However the same equipment and techniques used to fabricate the conventional materials serve equally as well for 21-6-9. No special techniques or procedures were used in the processing of the 21-6-9 specimens.

The results of the tests conducted on the 21-6-9 specimens are shown in figures 93 through 95 and listed in tables 26 and 27 of the Appendix. Photomicrographs of the microstructure of 21-6-9 in various conditions are shown in fig-96.

The 21-6-9 sheet was found to have a uniform strain capability of 40% at room temperature, 56% at -110°F (194°K), 42% at -320°F (78°K) and only 3% at -423°F (20°K). Because its uniform strain capability was so low at -423°F (20°K), no 21-6-9 specimens were strained at that temperature.

For strains up to 40% (the room temperature strain capability of the 21-6-9 sheet), the most beneficial strengthening effect was obtained by straining at room temperature. Within the 40% range, a given amount of strain produced a higher tensile yield strength when the 21-6-9 was strained at room temperature than when it was strained at either of the cryogenic temperatures. At the cryogenic temperatures, higher ultimate tensile strengths were developed. Consequently, for strains of 40% and less, straining 21-6-9 at room temperature produces more beneficial results than does cryostraining.

The one advantage that can be gained from cryostraining 21-6-9 is that at -110°F (194°K) and at -320°F (78°K) it can be uniformly strained more than 40%. Thus higher tensile strengths can be developed at those temperatures than at room temperature. Except for the additional uniform strain capability that the material has at cryogenic temperatures, cryostraining of 21-6-9 is not beneficial.

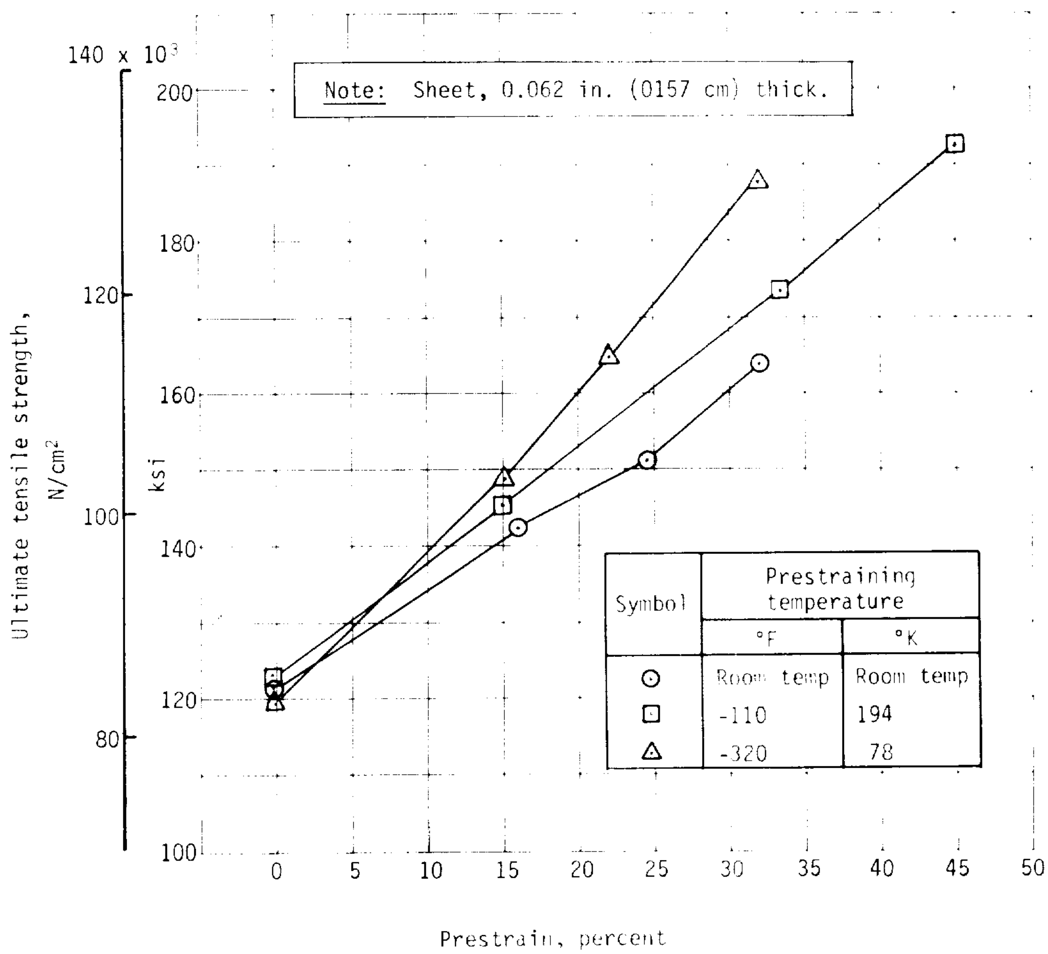


Figure 93.- Ultimate Tensile Strength of Prestrained 21-6-9 Corrosion Resistant Steel

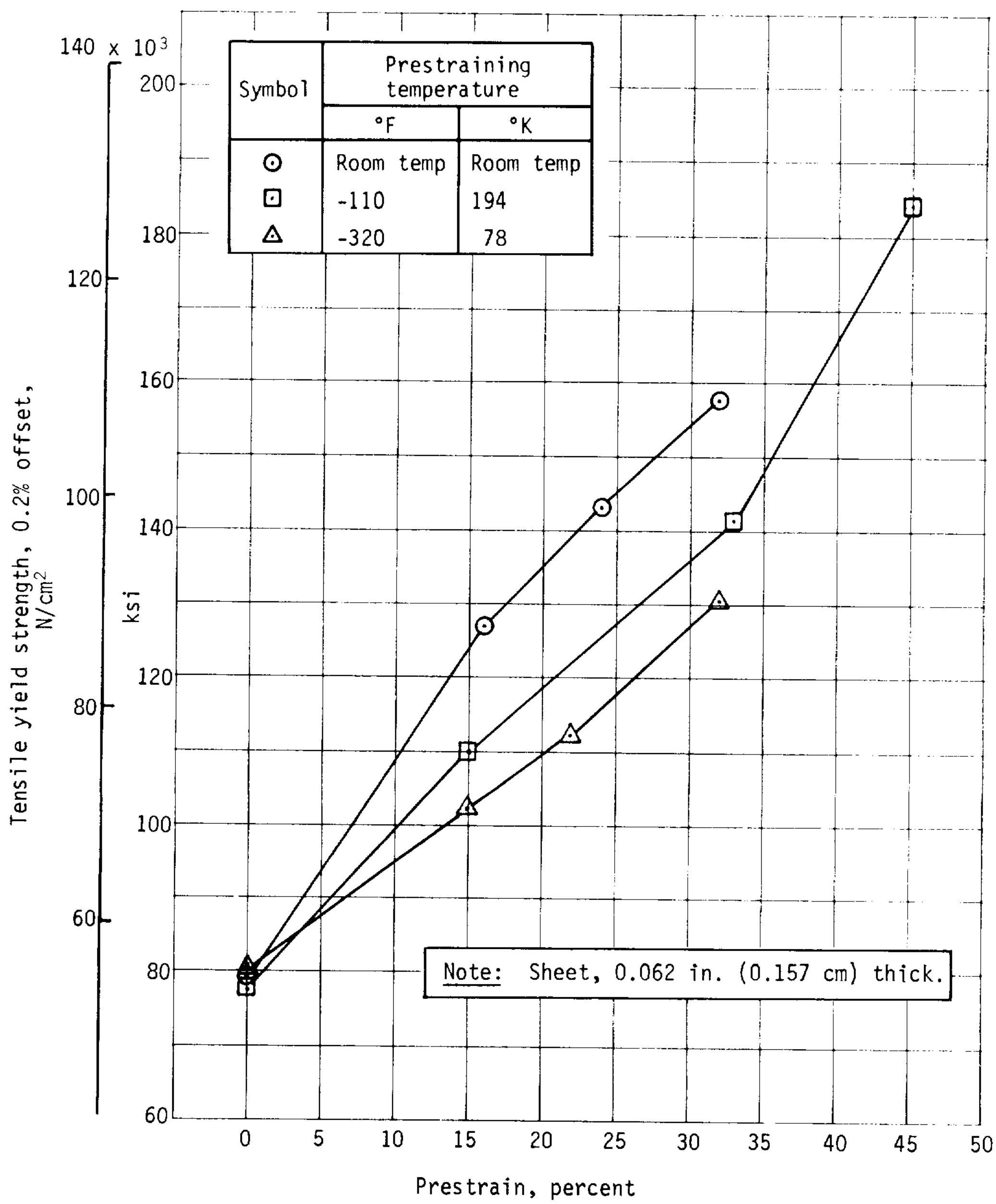


Figure 94.- Tensile Yield Strength of Prestrained 21-6-9 Corrosion Resistant Steel

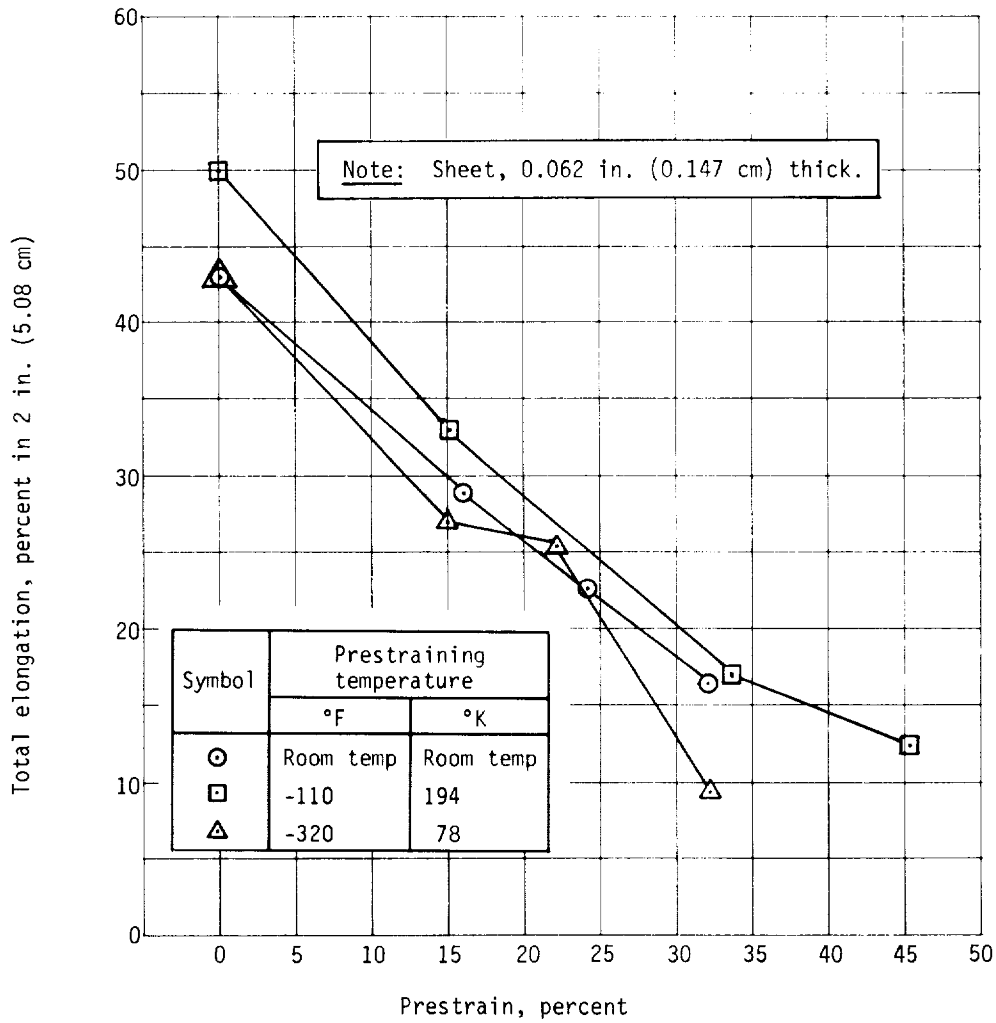
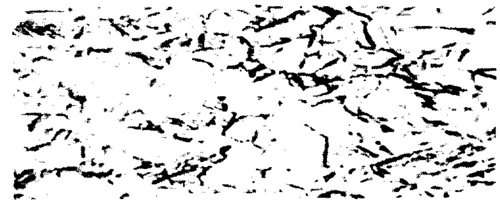


Figure 95.- Total Elongation of Prestrained 21-6-9 Corrosion Resistant Steel

(a) Soaked at Room Temperature, Unaged

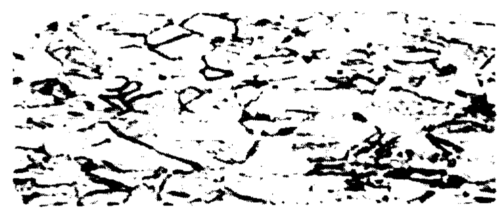


(b) 32% Strain at Room Temperature, Unaged

(c) 45% Strain at -110°F (194°K), Unaged

(d) 15% Strain at -320°F (78°K), Unaged

(e) 32% Strain at -320,F (78°K), Unaged



(f) Soaked at -423°F (20°K), Unaged

Note: The structure remained fully austenitic and only showed more twinning as a direct result of increased strain.

Electroetch: HCL + Methanol 500X

Figure 96.- Microstructure of 21-6-9 Corrosion Resistant Steel

5Aℓ-2.5Sn ELI Titanium Alloy

A sheet of annealed 5Aℓ-2.5Sn ELI titanium alloy measuring 0.071x36x96 in. (0.180x91x244 cm) was procured to material specfication AMS 4909B. The chemical composition of the sheet was:

Element	Percent by Weight
C	0.015
Fe	0.07
N_2	0.012
Aℓ	5.50
H_2	0.013
Sn	2.70
Mn	0.003
O_2	0.08
Ti	Balance

Density: 0.162 lb/cu in.; 4.48 gm/cc

The 5Aℓ-2.5Sn ELI titanium alloy specimens were prepared and processed in the normal manner described in Chapter III.

The results of the test conducted on the 5Aℓ-2.5Sn ELI titanium alloy specimens are given in figures 97 through 99 and in tables 28 and 29 of the Appendix. Figure 100 shows photomicrographs of the microstructure of the 5Aℓ-2.5 Sn ELI in various strained and unstrained conditions.

Cryostraining is not a practical method of strengthening 5Aℓ-2.5Sn ELI titanium alloy sheet. Higher tensile strengths can be developed at -320°F (78°K) by making use of the material's higher uniform strain capability at that temperature. However, a comparison of the properties of the specimens that had been strained 8.5% at room temperature (85% of the material's room temperature uniform strain capability) with the properties of the specimens that had been strained 12% at -320°F (78°K) (80% of the material's uniform strain capability) shows that the tensile yield strength of the specimens strained at -320°F (78°K) was only 4900 psi (3380 N/cm^2) higher (3.8%) than that of the specimens that had been strained at room temperature. Cryostraining 5Aℓ-2.5Sn ELI titanium alloy sheet offers no significant advantages.

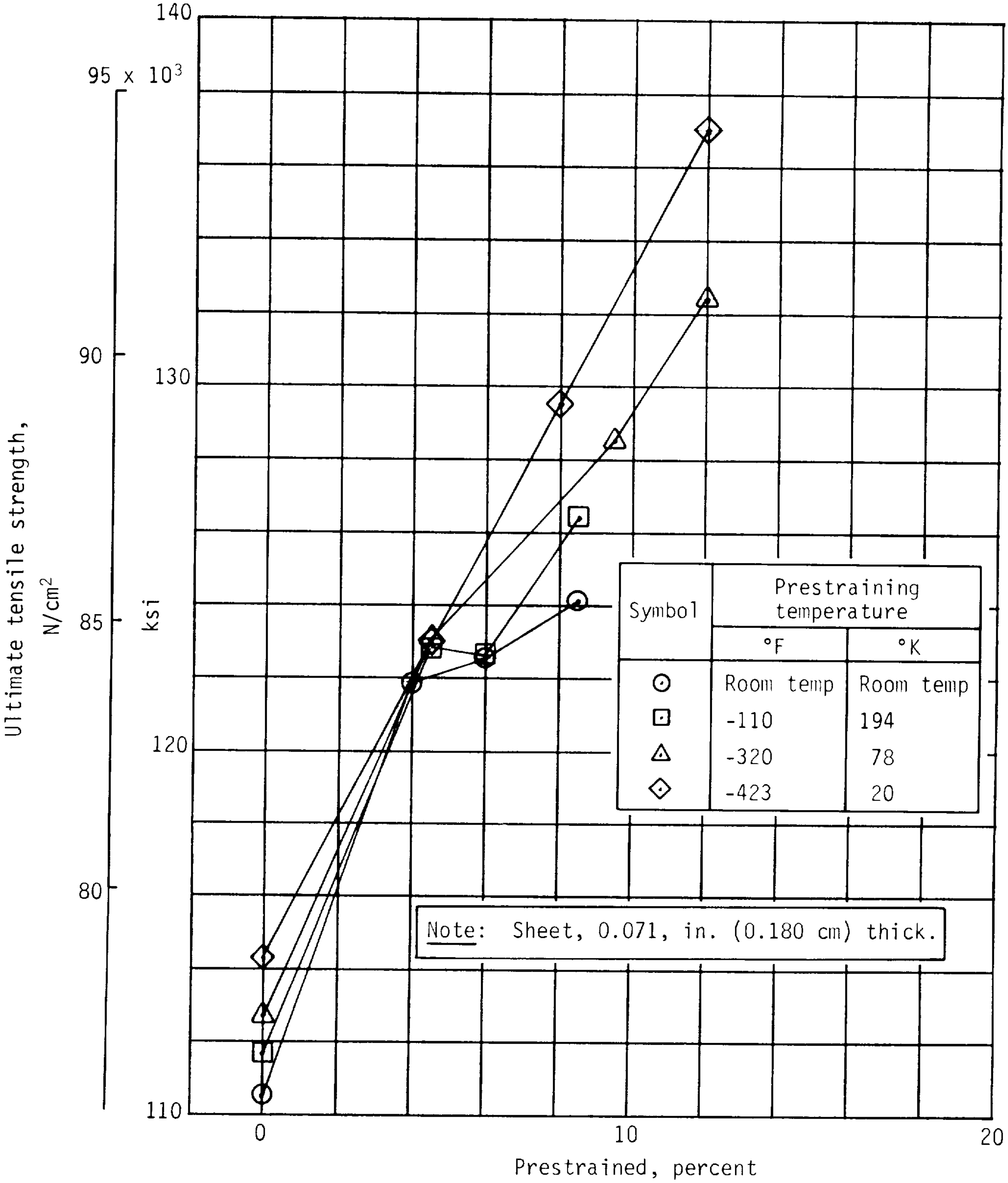


Figure 97.- Ultimate Tensile Strengtn of Prestrained 5Aℓ-2.5Sn ELI Titanium Alloy

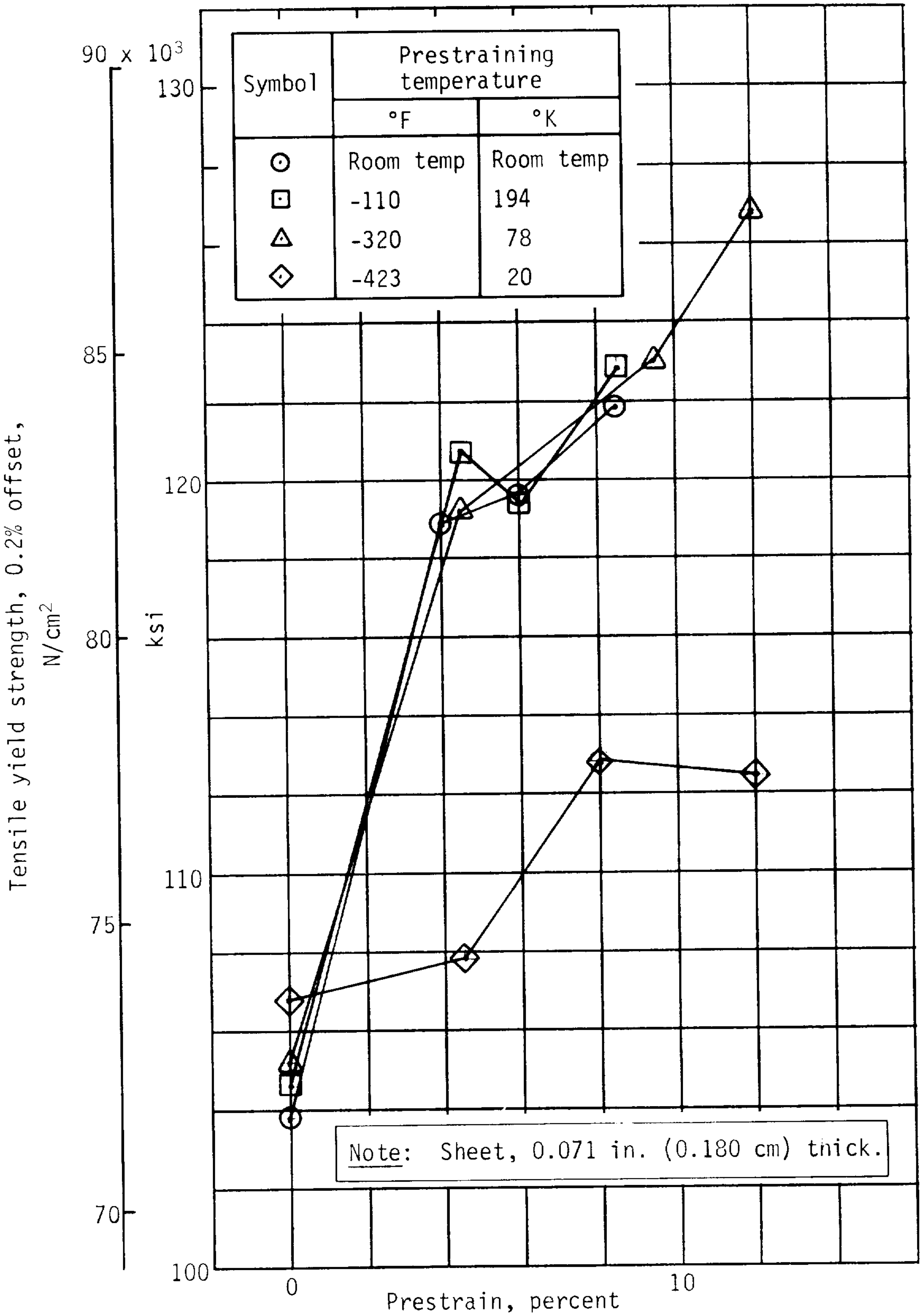


Figure 98.- Tensile Yield Strength of Prestrained 5Aℓ-2.5Sn ELI Titanium Alloy

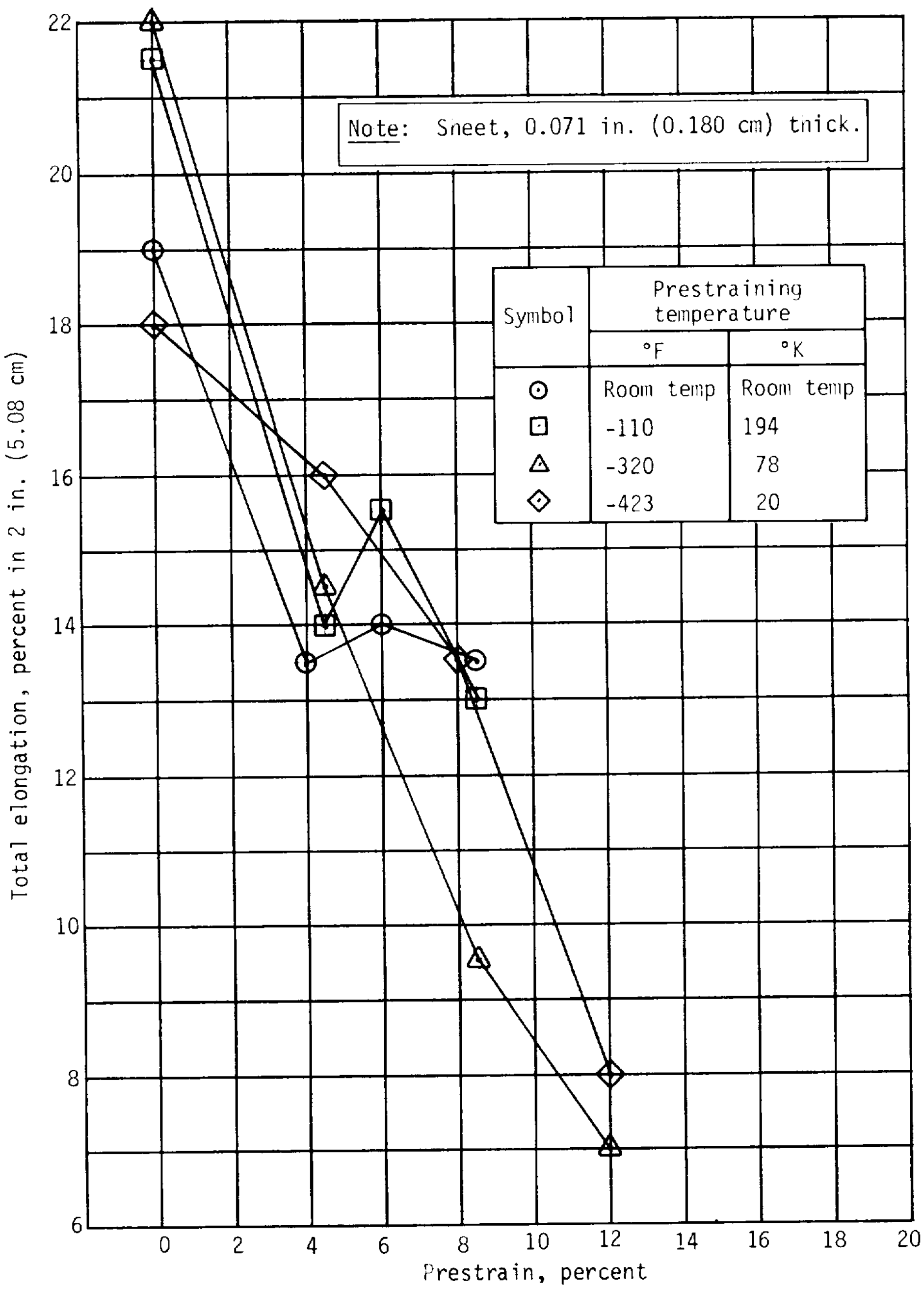
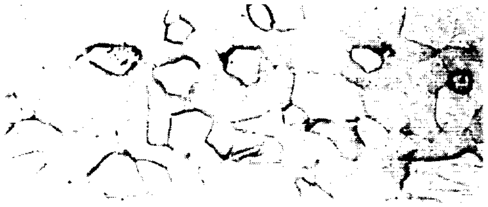
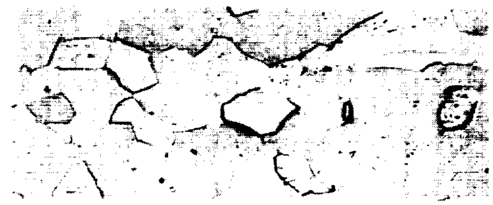


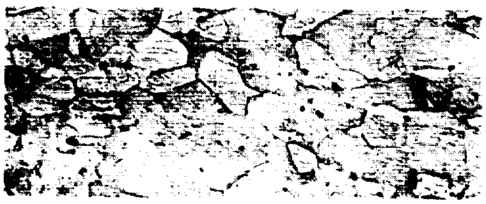
Figure 99.- Total Elongation of Prestrained 5Aℓ-2.5Sn ELI Titanium Alloy



(a) Room Temperature Soak, Unaged

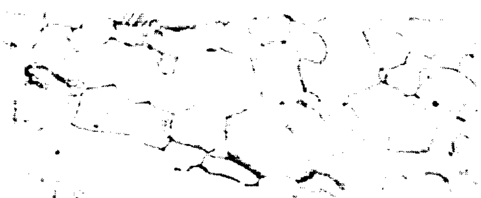


(b) 8.5% Strain at Room Temperature, Unaged



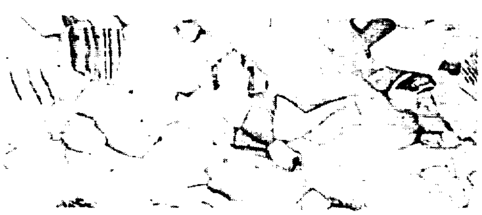
(c) Soaked at -110°F (194°K), Unaged

(d) 8.5% Strain at -110°F (194°K), Unaged



(e) Soaked at -320°F (78°K), Unaged

(f) 12% Strain at -320°F (78°K), Unaged



(g) Soaked at -423°F (20°K), Unaged

(h) 12% Strain at -423°F (20°K), Unaged

Note: The effects of straining at different temperatures are not manifest by observable changes to the all alpha microstructure.

Etch: HNO_3 - HF

500X

Figure 100.- Microstructure of 5Aℓ-2.5Sn ELI Titanium Alloy

6Aℓ-4V ELI Titanium Alloy

A 0.071x36x96 in. (0.180x91x244 cm) sheet of annealed 6Aℓ-4V ELI titanium alloy was procured to material specification AMS 4907B. The chemical composition of the sheet is:

Element	Percent by weight
C	0.023
Fe	0.10
N_2	0.011
Aℓ	5.90
Va	4.00
H_2	0.005
O_2	0.10
Ti	Balance

Density 0.160 lb/cu in.; 4.43 gm/cc

Because the 6Aℓ-4V ELI titanium alloy was procured in the annealed condition it was necessary to solution treat the material before it could be strained. The solution treatment specified was 1 hr at 1750°F (7220°K), water quench (5-sec maximum quench delay time), and the appropriate measures were to be taken to protect against interstitial contamination. It was necessary to subcontract the solution treatment of this material and the process requirements were not met. A vacuum furnace was used with the result that the quench-delay time exceeded the specified 5 sec. The too slowly cooled (slack quenched) material developed lower than normal properties, a condition that influenced the results of all subsequent tests conducted on the 6Aℓ-4V ELI material. However, the comparative value of the results were considered to be adequate.

During solution treatment the surface material was also contaminated and an alpha case was developed. Examination of the microstructure showed that the case depth was 0.003 in. (0.008 cm). Consequently, all of the 6Aℓ-4V ELI specimens were chem-milled after they has been machined and no less than 0.005 in. (0.013 cm) of stock was removed from all surfaces.

The 6Aℓ-4V ELI sheet material had such low uniform strain capability at -320°F (78°K) and at -423°F (20°K) that no specimens were strained at those temperatures. Also, again because of low uniform strain capability, 6Aℓ-4V specimens were strained to only two, rather than three, strain levels at -110°F (194°K), and to only one level of room temperature. Even at the latter temperatures the standard (for this program) strain rate of 0.050 in./in./minute (0.050 cm/cm/minute) was not used in straining the specimens; instead a strain rate of 0.005 in./in./min (0.005 cm/cm/minute) was used.

The standard aging treatment of 4 hr at 1000°F (812°K) was given the 6Aℓ-4V specimens that were aged. Before aging, the specimens were thoroughly cleaned and coated with a protective lacquer.

The results of the tests conducted on the 6Aℓ-4V ELI specimens are given in figures 101 through 106, and are listed in tables 30 and 31 of the Appendix. Figure 107 shows photomicrographs of the microstructure of the 6Aℓ-4V sheet material in various conditions.

The 6Aℓ-4V ELI sheet material had low uniform strain capability at room temperature and lower still at the cryogenic temperatures. This material is not suitable for cryostraining.

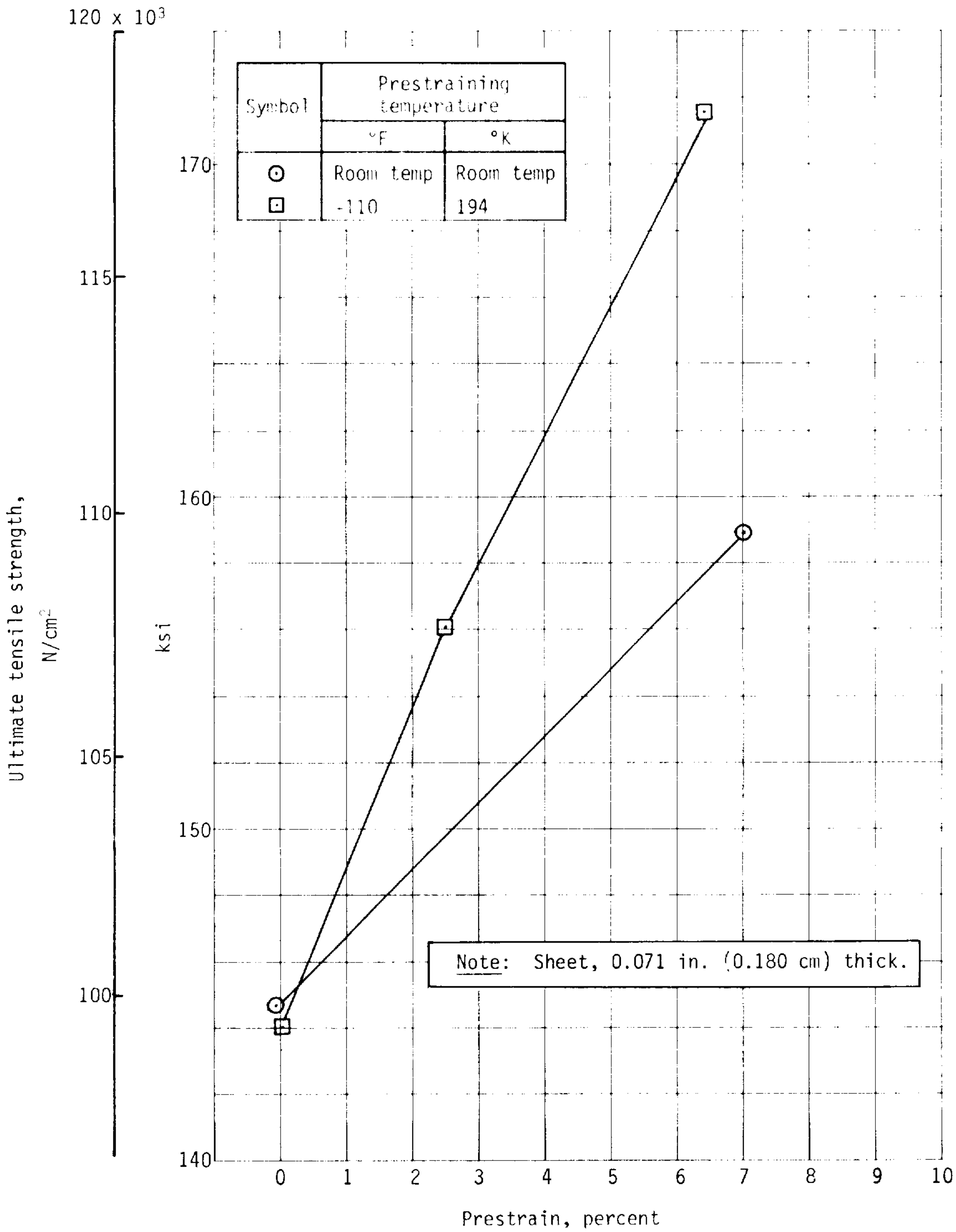


Figure 101.- Ultimate Tensile Strength of Prestrained 6Aℓ-4V ELI Titanium Alloy

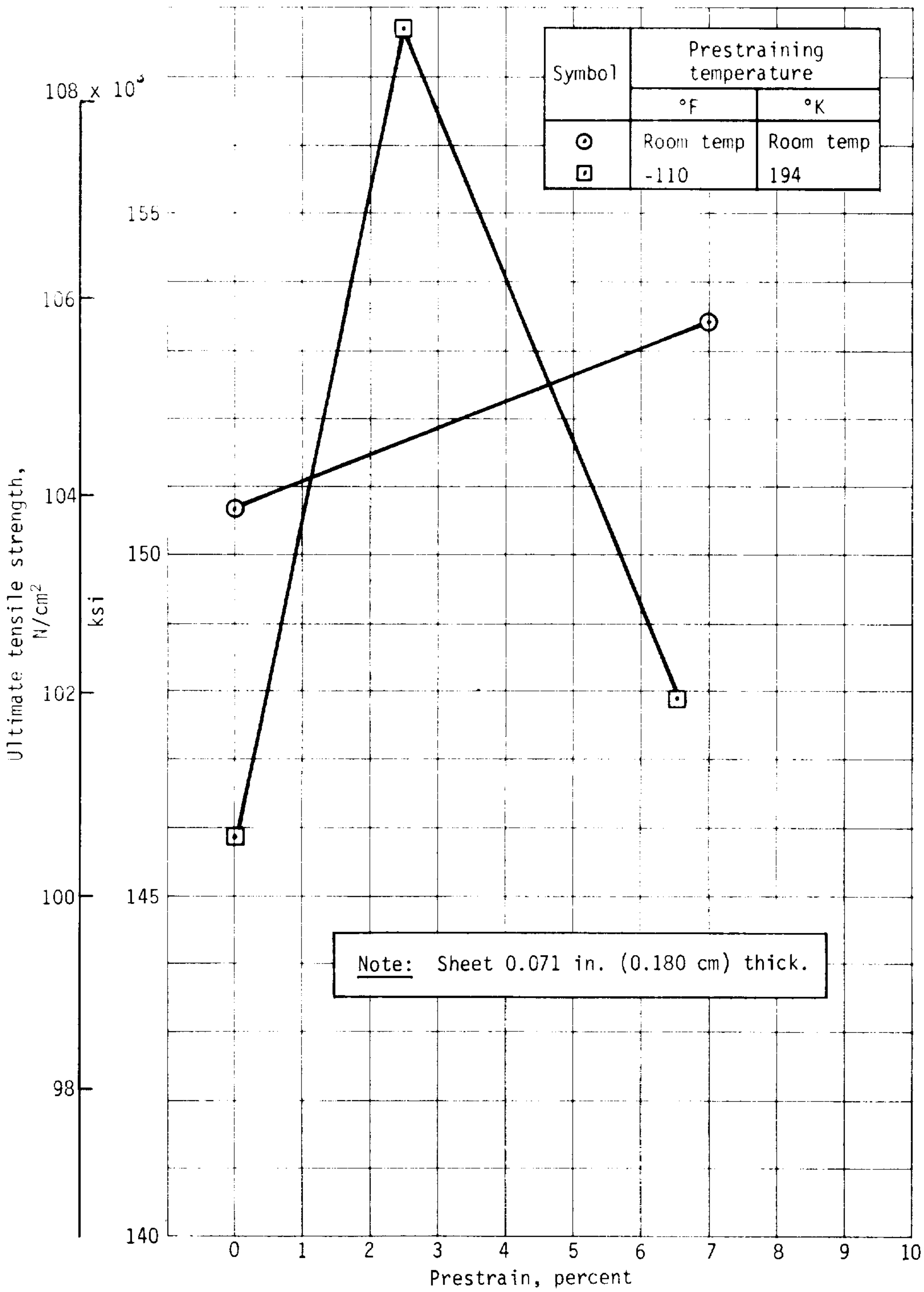


Figure 102.- Ultimate Tensile Strength of Prestrained 6Aℓ-4V ELI Titanium Alloy, Aged 4 hr at 1000°F (812°K)

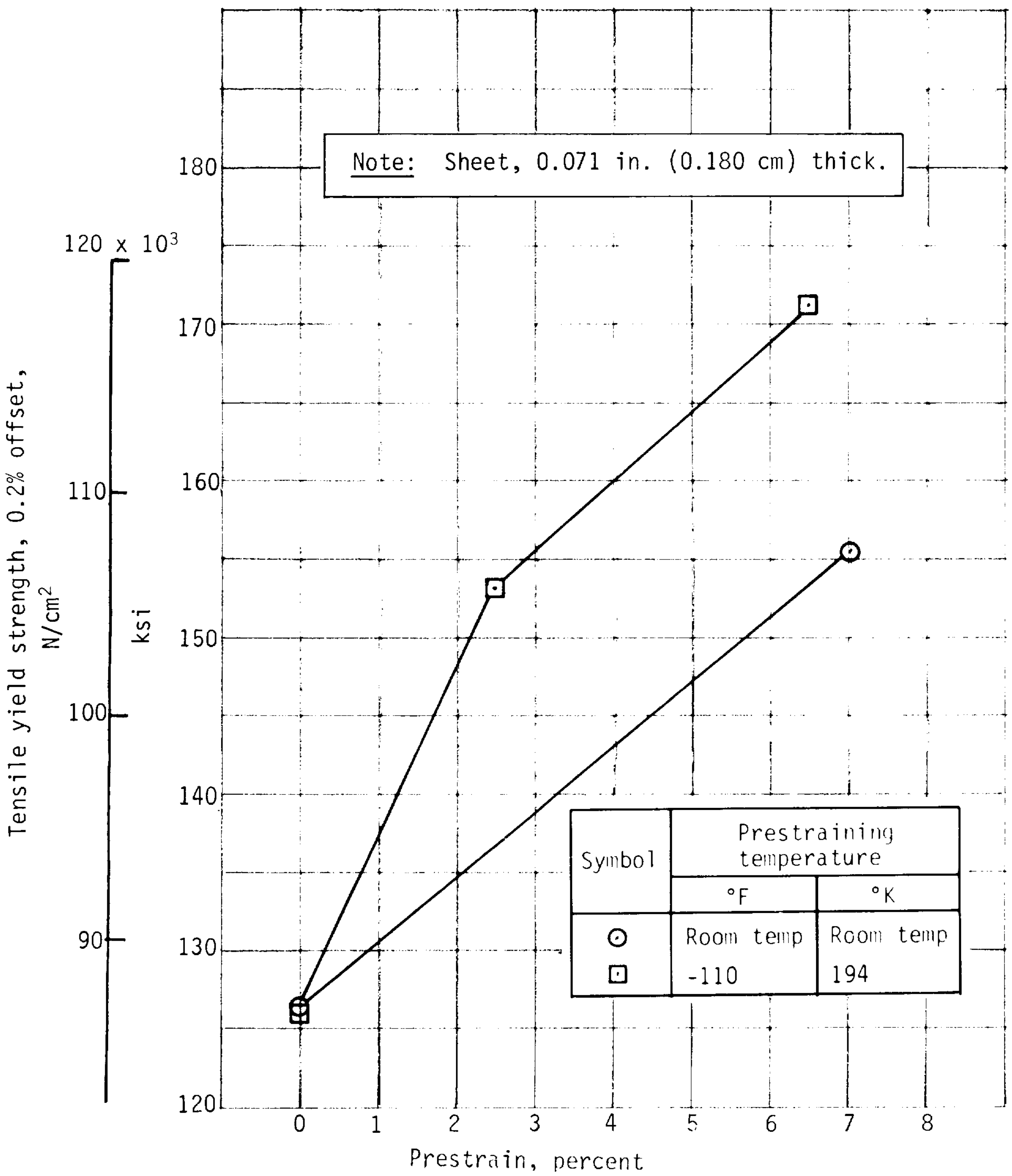


Figure 103.- Tensile Yield Strength of Prestrained 6Aℓ-4V ELI Titanium Alloy

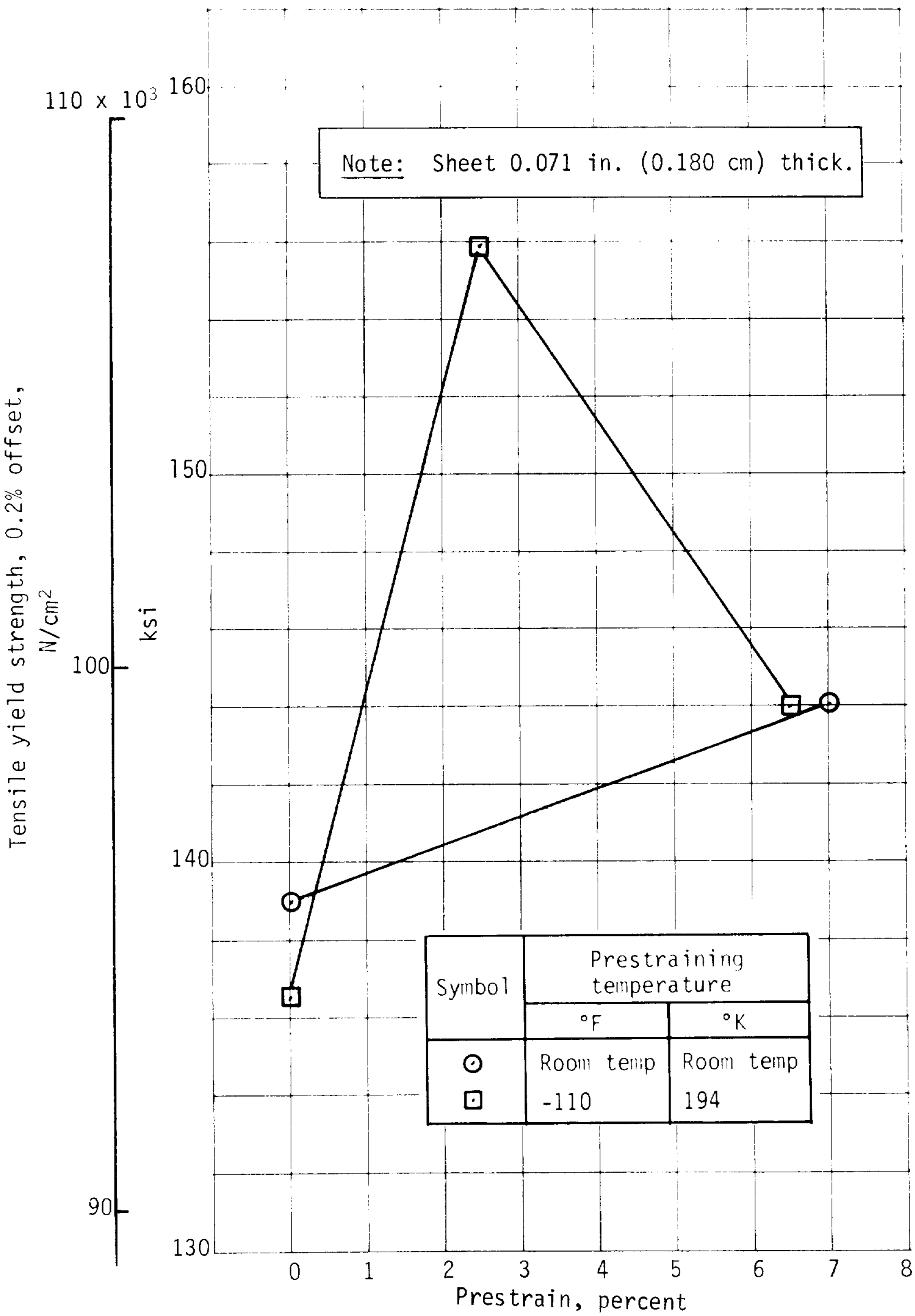


Figure 104.- Tensile Yield Strength of Prestrained 6Aℓ-4V ELI Titanium Alloy, Aged 4 hr at 1000°F (812°K)

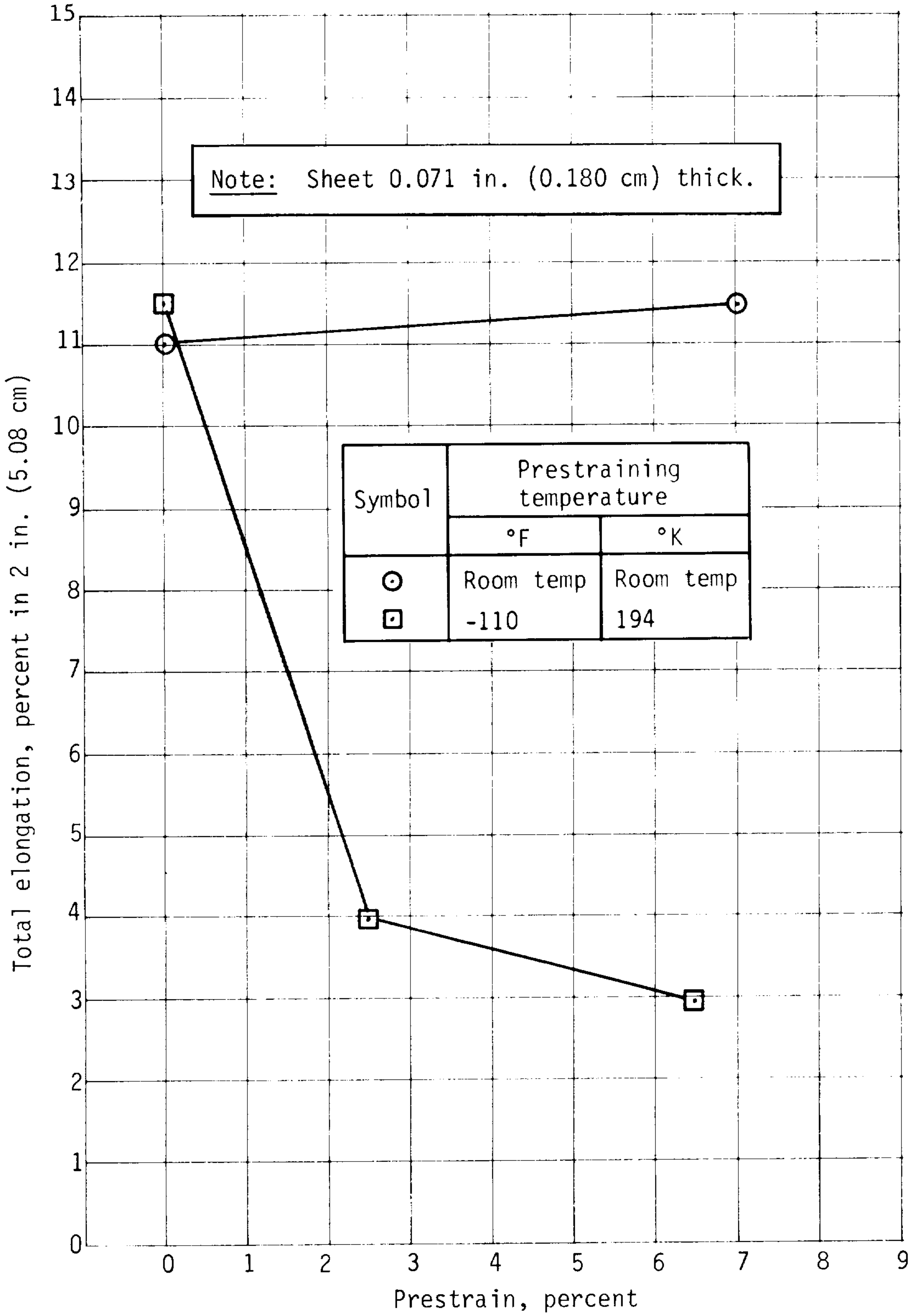


Figure 105.- Total Elongation of Prestrained 6Aℓ-4V ELI Titanium Alloy

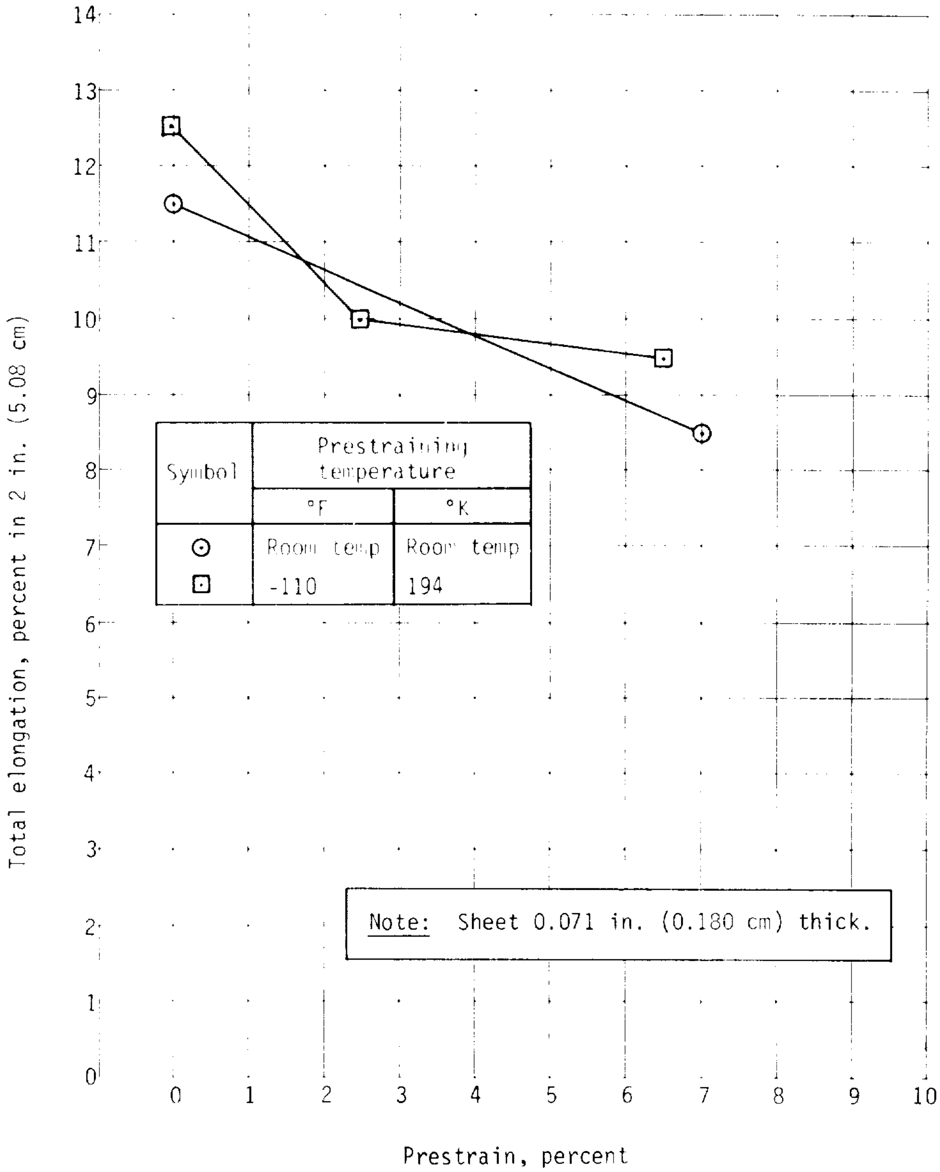


Figure 106.- Total Elongation of Prestrained 6Al-4V Titanium ELI Alloy, Aged 4 hr at 1000°F (812°K)

(a) Soaked at Room Temperature, Aged 4 hr at 1000°F (812°K)

(b) 7% Strain at Room Temperature, Aged 4 hr at 1000°F (812°K)

(c) Soaked at -110°F (194°K), Unaged

(d) Soaked at -110°F (194°K), Aged 4 hr at 1000°F (812°K)

(e) 7% Strain at Room Temperature, Unaged

(f) 6.5% Strain at -110°F (194°K), Aged 4 hr at 1000°F (812°K)

(g) 2.5% Strain at -110°F (194°K), Aged

(h) 6.5% Strain at -110°F (194°K), Unaged

Note: The appearance of the microstructure was not affected by straining.

Etch: HNO_3 - HF

500X

Figure 107.- Microstructure of 6Aℓ-4V ELI Titanium Alloy

V. CONCLUSIONS

Fifteen metallic alloys were tested to determine which of them could be significantly strengthened through cold working at cryogenic temperatures. The alloys tested were 2219 aluminum, 5456 aluminum, 6061 aluminum, beryllium copper, L-605 cobalt, MP 35 N cobalt-nickel, LA141A magnesium, Inconel 718, Nickel 440, A-286 corrosion resistant steel, PH 14-8 Mo corrosion resistant steel, TRIP steel, 21-6-9 corrosion resistant steel, 6Al-4V ELI titanium, and 5Al-2.5Sn ELI titanium.

For only two of the 15 alloys was straining at cryogenic temperatures found to be a significantly better strengthening treatment than room temperature straining. These two alloys were PH 14-8 Mo, a precipitation hardening semi-austenitic stainless steel, and MP 35 N, a cobalt-nickel multiphase alloy. Both of these alloys are strengthened by phase transformation. PH 14-8 Mo in the annealed (solution treated) condition has an austenitic structure. The austenite can be transformed to martensite either by thermal treatment or by cold working. The structure of annealed MP 35 N is face-centered cubic. When it is strained, platelets of a close-packed hexagonal phase form within the original structure. The test results indicate that, compared with room temperature straining effects, straining at cryogenic temperatures enhanced the strain induced phase transformation of both alloys.

It was found that seven other alloys, 6061 aluminum, 5456 aluminum, Inconel 718, Nickel 440, beryllium copper, A-286, and 21-6-9, could be strained greater amounts when the straining was done at cryogenic temperatures rather than at room temperature. Because of the additional strain capability at the cryogenic temperatures, these alloys can be strain hardened to higher strengths at cryogenic temperatures than at room temperatures.

For the other five alloys cryostraining was found to be of no benefit.

Specific conclusions reached as a result of this study are:

1) Cryostraining, compared to room temperature straining, is a truly beneficial strengthening process only for those metallic alloys that are strengthened by a strain-induced phase transformation that is enhanced when the material is strained at cryogenic temperatures;

2) Cryostraining is not necessarily a practical method of strengthening alloys that have a higher strain capability at cryogenic temperatures than room temperature when a strain-induced transformation does not occur along with strain hardening because the gains in strength are slight compared to the loss of elongation;

3) The response to cryostraining demonstrated by both PH 14-8 Mo and MP 35 N is sufficient to merit continued investigation of the effects of cryostraining on their mechanical and physical properties and those of similar alloys;

4) Light microscopy techniques do not appear to be adequate to distinguish the more subtle changes in microstructure in alloys where strain-induced transformations resulting from cryostraining produce significant strengthening.

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APPENDIX

TENSILE PROPERTIES TABLES

TABLE 2

TENSILE PROPERTIES OF 2219 ALUMINUM ALLOY SHEET[a]

(Unstrained and prestrained conditions[b])

Test temperature, F	Exposure or prestrain temperature, F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Tensile properties: Ultimate strength, psi	Tensile properties: Yield strength, 0.2 offset, psi	Tensile properties: Elongation, percent in 2 in., Total	Tensile properties: Elongation, percent in 2 in., Uniform
RT[c]	---	---	---	---	47 [illegible]	[illegible]	25.0	21.[illegible]
-110[c]	---	---	---	---	41 [illegible]	---	25.0	16.0
-320[c]	---	---	---	---	[illegible]	---	43.5	[illegible]
-423[c]	---	---	---	---	---	---	---	36.0
RT[d]	RT	21.0	0	0	48 500	21 [illegible]	24.5	---
RT[e]			0	0	54 300	34 [illegible]	12.0	---
RT[f]			7.0	7.0	52 500	42 [illegible]	17.0	---
RT[g]			7.0	7.[illegible]	65 400	53 4[illegible]	1[illegible]	---
RT[h]			7.0	7.5	6[illegible] 500	[illegible]	[illegible]	---
RT[f]			12.5	12.0	55 000	4[illegible]	[illegible]	---
RT[g]			12.5	12.[illegible]	66 [illegible]	[illegible]	9.0	---
RT[h]			12.5	13.[illegible]	66 9[illegible]	54 5[illegible]	[illegible]	---
RT[f]			17.[illegible]	17.3	55 300	53 [illegible]	[illegible]	---
RT[g]			17.[illegible]	17.[illegible]	[illegible]	[illegible]	[illegible]	---
RT[h]	RT	[illegible]	17.[illegible]	17.[illegible]	[illegible]	[illegible]	[illegible]	---
RT[d]	-110	15.[illegible]	0	0	45 900	[illegible]	23.5	---
RT[e]			0	0	54 100	55 300	11.5	---
RT[f]			7.[illegible]	7.0	53 0[illegible]	42 1[illegible]	18.0	---
RT[g]			7.[illegible]	7.0	65 7[illegible]	55 10[illegible]	11.0	---
RT[h]			7.[illegible]	7.5	6[illegible]	55 [illegible]	11.0	---
RT[i]			11.0	12.[illegible]	54 [illegible]	46 700	13.0	---
RT[g]	-110	1[illegible]	11.0	12.[illegible]	65 [illegible]	52 [illegible]	11.[illegible]	---

TABLE 2. - Continued

TENSILE PROPERTIES OF 2219 ALUMINUM ALLOY SHEET[a]

(Unstrained and prestrained conditions[b])

Test temperature, °F	Exposure or prestrain temperature, °F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Tensile properties: Ultimate strength, psi	Tensile properties: Yield strength, 0.2 offset, psi	Tensile properties: Elongation, percent in 2 in.: Total	Tensile properties: Elongation, percent in 2 in.: Uniform
RT^{h}	-110	18.0	11.0	12.0	66 600	53 900	11.5	---
RT^{f}			14.5	15.0	56 400	48 600	11.0	---
RT^{g}			14.5	14.5	65 200	53 300	10.0	---
RT^{h}	-110	18.0	14.5	14.5	65 900	53 500	9.5	---
RT^{d}	-320	35.0	0	0	48 800	22 600	24.0	---
RT^{e}			0	0	53 500	33 500	11.5	---
RT^{f}			7.0	7.0	52 600	44 200	15.5	---
RT^{g}			7.0	7.0	64 900	52 100	11.0	---
RT^{h}			7.0	7.5	65 900	53 500	11.5	---
RT^{f}			21.0	21.0	61 100	57 400	7.5	---
RT^{g}			21.0	21.5	66 000	54 800	10.0	---
RT^{h}			21.0	21.0	66 700	55 500	11.0	---
RT^{f}			28.0	29.0	64 400	60 900	5.5	---
RT^{g}			28.0	27.0	65 400	55 000	10.0	---
RT^{h}	-320	35.0	28.0	26.5	66 100	55 700	9.5	---
RT^{d}	-423	36.0	0	0	48 300	21 600	24.5	---
RT^{e}			0	0	53 900	33 300	12.0	---
RT^{f}			7.0	7.0	52 800	44 400	16.0	---
RT^{g}			7.0	6.0	65 600	51 200	11.5	---
RT^{h}			7.0	6.0	66 000	53 400	11.0	---
RT^{f}			21.5	19.0	60 000	59 700	5.0	---
RT^{g}	-423	36.0	21.5	21.0	66 200	53 300	11.0	---

TABLE 2. - Concluded

TENSILE PROPERTIES OF 2219 ALUMINUM ALLOY SHEET[a]

(Unstrained and prestrained conditions[b])

Test temperature, °F	Exposure or prestrain temperature, °F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Tensile properties			
					Ultimate strength, psi	Yield strength, 0.2% offset, psi	Elongation, percent in 2 in.	
							Total	Uniform
RT[h]	-423	36.0	21.5	21.0	67 600	56 600	10.0	---
RT[f]			29.0	29.5	66 100	---	2.0	---
RT[g]			29.0	26.5	66 500	55 600	10.5	---
RT[h]	-423	36.0	29.0	26.5	66 500	55 700	10.5	---

[a]Sheet, 0.080 inch thick.

[b]All specimens were machined from annealed material. They were then solution treated (50 minutes at 995°F), water quenched, and immediately refrigerated and stored at -30°F.

[c]Condition: The specimens were removed from the refrigerator, exposed to the indicated temperature until the temperature of the specimens had stabilized at that temperature. They were tested within 15 minutes after thermal equilibrium had been achieved.

[d]Condition: The specimens were removed from the refrigerator, exposed to the indicated temperature, and were then naturally aged at room temperature for no less than seven days before being tested.

[e]Condition. Same as "d", except that after being naturally aged the specimens were precipitation heat treated (30 hours at 375°F) and then tested.

[f]Condition: The specimens were removed from the refrigerator, exposed to the indicated temperature and pre-strained at that temperature within 15 minutes after thermal equilibrium was achieved, and then were naturally aged at room temperature for no less than 7 days before being tested.

[g]Condition: Same as "f", except that after being naturally aged the specimens were precipitation heat treated (24 hours at 325°F) and then tested.

[h]Condition: Same as "f", except that after being naturally aged the specimens were precipitation heat treated (18 hours at 325°F) and then tested.

TABLE 3

TENSILE PROPERTIES OF 2219 ALUMINUM ALLOY SHEET[a]

(Unstrained and prestrained conditions[b])

Test temperature, °K	Exposure or prestrain temperature, °K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Tensile properties: Ultimate strength, N/cm	Tensile properties: Yield strength, 0.2% offset, N/cm	Tensile properties: Elongation, percent in 5.08 cm: Total	Tensile properties: Elongation, percent in 5.08 cm: Uniform
RT[c]	---	---	---	---	32 500	12 500	25.0	21.0
194[c]	---	---	---	---	28 400	---	25.0	18.0
78[c]	---	---	---	---	39 900	---	43.5	35.0
20[c]	---	---	---	---	---	---	---	36.0
RT[d]	RT	21.0	0	0	33 400	14 900	24.5	---
RT[e]			0	0	37 400	23 500	12.0	---
RT[f]			7.0	7.0	36 300	29 500	17.0	---
RT[g]			7.0	7.0	45 100	36 800	10.0	---
RT[h]			7.0	7.5	47 200	38 000	10.0	---
RT[f]			12.5	12.0	38 300	33 600	13.0	---
RT[g]			12.5	12.5	45 600	37 000	9.0	---
RT[h]			12.5	13.0	46 100	37 800	10.0	---
RT[f]			17.0	17.5	40 200	37 000	9.5	---
RT[g]			17.0	17.0	45 200	37 400	8.0	---
RT[h]	RT	21.0	17.0	17.0	45 400	37 700	9.0	---
RT[d]	194	18.0	0	0	33 700	15 400	23.5	---
RT[e]			0	0	37 300	23 000	11.5	---
RT[f]			7.0	7.0	36 500	29 000	18.0	---
RT[g]			7.0	7.0	45 300	36 600	11.0	---
RT[h]			7.0	7.5	44 400	36 500	11.0	---
RT[f]			11.0	12.0	37 800	32 200	13.0	---
RT[g]	194	18.0	11.0	12.0	45 400	36 500	11.0	---

TABLE 3. - Continued

TENSILE PROPERTIES OF 2219 ALUMINUM ALLOY SHEET[a]

(Unstrained and prestrained conditions[b])

Test temperature, K	Exposure or prestrain temperature, K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Tensile properties: Ultimate strength, N/cm²	Tensile properties: Yield strength, 0.2% offset, N/cm²	Elongation, percent in 5.08 cm: Total	Elongation, percent in 5.08 cm: Uniform
RT[h]	194	18.0	11.0	12.0	45 900	37 200	11.5	---
RT[f]			14.5	15.0	38 900	33 500	11.0	---
RT[g]			14.5	14.5	43 000	36 600	10.0	---
RT[h]	194	18.0	14.5	14.5	43 400	37 100	9.5	---
RT[d]	78	35.0	0	0	33 600	15 500	24.0	---
RT[e]			0		36 900	23 100	11.5	---
RT[f]			7.0	7.0	36 300	30 500	15.5	---
RT[g]			7.0	7.[illegible]	[illegible] 700	35 900	11.0	---
RT[h]			7.0	7.5	45 400	36 900	[illegible].5	---
RT[f]			21.0	21.0	42 100	[illegible]	7.5	---
RT[illegible]			21.0	21.5	45 500	37 [illegible]	[illegible]	---
RT[h]			21.0	21.[illegible]	46 300	[illegible]	[illegible]	---
RT[f]			28.0	29.[illegible]	44 400	42 [illegible]	[illegible]	---
RT[g]			28.0	[illegible]	45 1[illegible]	37 [illegible]	[illegible]	---
RT[h]	78	35.0	28.0	[illegible].5	[illegible]	[illegible]	[illegible].5	---
RT[illegible]	20	[illegible]			33 [illegible]	[illegible]	[illegible]	---
RT[e]				[illegible]	37 200	[illegible]	11.[illegible]	---
RT[f]			7.0	7.[illegible]	[illegible]	[illegible]	10.[illegible]	---
RT[g]			7.0	[illegible]	45 200	[illegible]	11.5	---
RT[h]			7.0	[illegible]	43 500	[illegible]	[illegible]	---
RT[f]			21.5	19.[illegible]	41 400	42 [illegible]	[illegible]	---
RT[g]	20	34.0	21.5	21.[illegible]	[illegible]	36 700	11.0	---

TABLE 3. - Concluded

TENSILE PROPERTIES OF 2219 ALUMINUM ALLOY SHEET[a]

(Unstrained and prestrained conditions[b])

Test temperature, K	Exposure or prestrain temperature, K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Tensile properties			
					Ultimate strength, [illegible]	Yield strength, [illegible] offset, [illegible]	Elongation, percent in 5.08 cm	
							Total	Uniform
RT[e]	20	36.[illegible]	21.5	21.0	[illegible]	3[illegible]	1[illegible]	---
RT[f]	↕	↕	29.0	29.5	45 [illegible]	---	[illegible]	---
RT[g]	↕	↕	29.0	26.5	45 [illegible]	3[illegible]	1[illegible].5	---
RT[h]	20	36.0	29.0	26.5	45 [illegible]	3[illegible]	1[illegible]	---

[a]Sheet, 0.203 cm. thick.

[b]All specimens were machined from annealed material. They were then solution treated (50 minutes at 809°K), water quenched, and immediately refrigerated and stored at 239°K.

[c]Condition: The specimens were removed from the refrigerator, exposed to the indicated temperature until the temperature of the specimens had stabilized at that temperature. They were tested within 15 minutes after thermal equilibrium had been achieved.

[d]Condition: The specimens were removed from the refrigerator, exposed to the indicated temperature, and were then naturally aged at room temperature for no less than seven days before being tested.

[e]Condition: Same as "d", except that after being naturally aged the specimens were precipitation heat treated (36 hours at 463°K) and then tested.

[f]Condition: The specimens were removed from the refrigerator, exposed to the indicated temperature and pre-strained at that temperature within 15 minutes after thermal equilibrium was achieved, and then were naturally aged at room temperature for no less than 7 days before being tested.

[g]Condition: Same as "f", except that after being naturally aged the specimens were precipitation heat treated (24 hours at 436°K) and then tested.

[h]Condition: Same as "f", except that after being naturally aged the specimens were precipitation heat treated ([illegible] hours at 436°K) and then tested.

TABLE 4

TENSILE PROPERTIES OF 5456 ALUMINUM ALLOY SHEET[a]

(Unstrained and prestrained conditions[b])

Test temperature, °F	Exposure or prestrain temperature, °F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Tensile properties			
					Ultimate strength, psi	Yield strength, 0.2% offset, psi	Elongation, percent in 2 in.	
							Total	Uniform
RT[c]	---	---	---	---	49 000	20 500	21.0	19.5
-110[c]	---	---	---	---	48 000	20 800	27.5	25.0
-320[c]	---	---	---	---	64 900	20 900	45.0	40.0
-423[c]	---	---	---	---	79 200	25 400	22.0	22.0
RT[d]	RT	19.5	0	0	48 100	20 400	22.0	---
RT[e]			8.0	8.0	51 400	42 400	14.0	---
RT[e]			11.5	11.5	54 000	45 300	11.5	---
RT[e]	RT	19.5	15.5	16.0	55 800	48 300	9.5	---
RT[d]	-110	25.0	0	0	47 800	21 000	21.5	---
RT[e]			8.0	7.0	50 500	40 500	14.5	---
RT[e]			15.0	15.5	55 400	47 900	10.0	---
RT[e]	-110	25.0	20.0	21.0	57 300	49 700	8.5	---
RT[d]	-320	40.0	0	0	50 700	21 300	21.5	---
RT[e]			8.0	8.0	52 000	42 100	14.0	---
RT[e]			24.0	24.0	60 700	55 900	6.5	---
RT[e]	-320	40.0	32.0	31.5	63 300	59 300	4.5	---
RT[d]	-423	22.0	0	0	46 900	20 600	22.0	---
RT[e]			8.0	8.0	51 900	43 900	13.0	---
RT[e]			13.0	12.0	54 300	50 200	9.0	---
RT[e]	-423	22.0	17.5	16.0	56 700	53 800	6.5	---

TABLE 4. - Concluded

TENSILE PROPERTIES OF 5456 ALUMINUM ALLOY SHEET[a]
(Unstrained and prestrained conditions[b])

Test temperature, °F	Exposure or prestrain temperature, °F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Tensile properties			
					Ultimate strength, psi	Yield strength, 0.2% offset, psi	Elongation, percent in 2 in.	
							Total	Uniform

[a]Sheet, 0.063 inch thick.

[b]All specimens were machined from annealed material.

[c]Condition: Annealed

[d]Condition: Annealed and exposed to the indicated temperature.

[e]Condition: Annealed and prestrained at the indicated temperature.

TABLE 5

TENSILE PROPERTIES OF 5456 ALUMINUM ALLOY SHEET[a]
(Unstrained and prestrained conditions[b])

Test temperature, K	Exposure or prestrain temperature, K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Tensile properties			
					Ultimate strength, N/cm	Yield strength, 0.2% offset, N/cm	Elongation, percent in 5.08 cm	
							Total	Uniform
RT[c]	---	---	---	---	33 800	14 100	21.0	19.5
194[c]	---	---	---	---	33 100	14 300	27.5	25.0
78[c]	---	---	---	---	44 700	14 400	45.0	40.0
20[c]	---	---	---	---	54 600	17 500	22.0	22.0
RT[d]	RT	19.5	0	0	33 200	14 100	22.0	---
RT[e]			8.0	8.0	35 400	29 200	14.0	---
RT[e]			11.5	11.5	37 200	31 200	11.5	---
RT[e]	RT	19.5	15.5	16.0	38 500	33 300	9.5	---
RT[d]	194	25.0	0	0	33 000	14 500	21.5	---
RT[e]			8.0	7.0	34 800	27 900	14.5	---
RT[e]			15.0	15.5	38 200	33 000	10.0	---
RT[e]	194	25.0	20.0	21.0	39 500	34 300	8.5	---
RT[d]	78	40.0	0	0	35 000	14 700	21.5	---
RT[e]			8.0	8.0	35 900	29 900	14.0	---
RT[e]			24.0	24.0	41 900	38 500	6.5	---
RT[e]	78	40.0	32.0	31.5	43 600	40 900	4.5	---
RT[d]	20	22.0	0	0	32 300	14 200	22.0	---
RT[e]			8.0	8.0	35 800	30 300	13.0	---
RT[e]			13.0	12.0	37 400	34 600	9.0	---
RT[e]	20	22.0	17.5	16.0	39 100	37 100	6.5	---

TABLE 5. - Concluded

TENSILE PROPERTIES OF 5456 ALUMINUM ALLOY SHEET[a]
(Unstrained and prestrained conditions[b])

Test temperature, °K	Exposure or prestrain temperature, °K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Tensile properties			
					Ultimate strength, N/cm²	Yield strength, 0.2% offset, N/cm²	Elongation, percent in 5.08 cm	
							Total	Uniform

[a]Sheet, 0.160 cm. thick.

[b]All specimens were machined from annealed material.

[c]Condition: Annealed.

[d]Condition: Annealed and exposed to the indicated temperature.

[e]Condition: Annealed and prestrained at the indicated temperature.

TABLE 6

TENSILE PROPERTIES OF 6061 ALUMINUM ALLOY SHEET[a]

(Unstrained and prestrained conditions[b])

Test temperature, °F	Exposure or prestrain temperature, °F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Tensile properties			
					Ultimate strength, psi	Yield strength, 0.2 offset, psi	Elongation, percent in 2 in.	
							Total	Uniform
RT[c]	---	---	---	---	26 100	8 900	26.5	21.0
-110[c]	---	---	---	---	26 300	---	30.0	22.0
-320[c]	---	---	---	---	---	---	48.0	42.0
-423[c]	---	---	---	---	---	---	---	43.0
RT[d]	RT	21.0	0	0	37 600	17 800	25.5	---
RT[e]			0	0	45 900	39 800	15.5	---
RT[f]			8.5	8.5	34 500	29 400	14.0	---
RT[g]			8.5	8.5	45 600	42 900	11.5	---
RT[f]			12.5	12.5	36 100	32 200	9.0	---
RT[g]			12.5	12.5	46 700	44 800	9.0	---
RT[f]			17.0	17.5	37 900	34 900	7.0	---
RT[g]	RT	21.0	17.0	17.0	44 300	43 100	9.0	---
RT[d]	-110	22.0	0	0	36 800	17 300	26.5	---
RT[e]			0	0	45 600	39 300	15.5	---
RT[f]			8.5	9.5	35 200	29 600	14.0	---
RT[g]			8.5	8.5	45 100	42 000	12.0	---
RT[f]			13.0	12.5	37 300	32 000	12.0	---
RT[g]			13.0	12.0	45 700	43 400	11.0	---
RT[f]			17.5	18.0	39 000	34 900	9.5	---
RT[g]	-110	22.0	17.5	17.5	45 900	44 200	8.0	---
RT[d]	-320	42.0	0	0	38 600	18 500	26.5	---
RT[e]			0	0	45 500	39 500	15.0	---
RT[f]			8.5	9.5	35 800	33 100	10.0	---
RT[g]	-320	42.0	8.5	8.5	45 100	42 800	11.5	---

TABLE 6. - Concluded

TENSILE PROPERTIES OF 6061 ALUMINUM ALLOY SHEET[a]

Unstrained and prestrained conditions[b]

Test temperature, °F	Exposure or prestrain temperature, °F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Tensile properties: Ultimate strength, psi	Tensile properties: Yield strength, 0.2% offset, psi	Elongation, percent in 2 in.: Total	Elongation, percent in 2 in.: Uniform
RT[f]	-320	42.0	25.0	25.5	43 900	43 100	4.5	---
RT[g]			25.0	24.5	48 300	48 100	9.0	---
RT[f]			33.5	32.5	45 900	45 400	2.5	---
RT[g]	-320	42.0	33.5	33.5	50 900	50 900	8.0	---
RT[d]	-423	43.0	0	0	35 700	17 000	25.0	---
RT[e]			0	0	45 800	39 800	15.0	---
RT[f]			8.5	8.0	34 500	31 600	15.5	---
RT[g]			8.5	9.0	45 100	43 500	11.5	---
RT[f]			26.0	23.0	43 100	---	2.5	---
RT[g]			26.0	25.0	50 800	50 700	5.0	---
RT[f]			34.0	29.0	46 200	45 300	2.5	---
RT[g]	-423	43.0	34.0	33.0	52 700	52 700	3.5	---

[a] Sheet, 0.090 inch thick.

[b] All specimens were machined from annealed material. They were then solution treated (one hour at 980°F), water quenched, and immediately refrigerated and stored at -30°F.

[c] Condition: The specimens were removed from the refrigerator, exposed to the indicated temperature until the temperature of the specimens had stabilized at that temperature. They were tested within 15 minutes after thermal equilibrium had been achieved.

[d] Condition: The specimens were removed from the refrigerator, exposed to the indicated temperature, and were then naturally aged at room temperature for no less than seven days before being tested.

[e] Condition: Same as "d," except that after being naturally aged the specimens were precipitation heat treated (16 hours at 320°F) and then tested.

[f] Condition: The specimens were removed from the refrigerator, exposed to the indicated temperature and prestrained at that temperature within 15 minutes after thermal equilibrium was achieved, and then were naturally aged at room temperature for no less than 7 days before being tested.

[g] Condition: Same as "f," except that after being naturally aged the specimens were precipitation heat treated (16 hours at 320°F) and then tested.

TABLE 7

TENSILE PROPERTIES OF 6061 ALUMINUM ALLOY SHEET[a]

(Unstrained and prestrained conditions[b])

Test temperature, K	Exposure or prestrain temperature, K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Tensile properties: Ultimate strength, N/cm	Tensile properties: Yield strength, 0.2% offset, N/cm	Tensile properties: Elongation, percent in 5.08 cm: Total	Tensile properties: Elongation, percent in 5.08 cm: Uniform
RT[c]	---	---	---	---	1[illegible] 000	6 100	26.5	21.0
194[c]	---	---	---	---	18 100	---	30.0	22.0
78[c]	---	---	---	---	---	---	48.0	42.0
20[c]	---	---	---	---	---	---	---	43.0
RT[d]	RT	21.0	0	0	25 900	12 300	25.5	---
RT[e]			0	0	31 600	27 400	15.5	---
RT[f]			8.5	8.5	23 800	20 300	14.0	---
RT[g]			8.5	8.5	31 400	29 600	11.5	---
RT[f]			12.5	12.5	24 900	22 200	9.0	---
RT[g]			12.5	12.5	32 200	30 [illegible]	9.0	---
RT[f]			17.0	17.5	26 100	[illegible]	7.5	---
RT[g]	RT	21.0	17.0	17.[illegible]	30 500	29 7[illegible]	[illegible]	---
RT[d]	194	[illegible]	[illegible]	[illegible]	25 400	11 900	[illegible]	---
RT[e]			[illegible]	[illegible]	31 400	27 100	13.5	---
RT[f]			8.5	[illegible]	2[illegible]	20 [illegible]	14.0	---
RT[g]			[illegible]	[illegible]	31 [illegible]	29 [illegible]	12.0	---
RT[f]			13.0	12.5	25 700	22 1[illegible]	12.0	---
RT[g]			13.0	12.0	31 500	29 [illegible]	11.0	---
RT[f]			17.5	18.0	26 900	24 1[illegible]	9.5	---
RT[g]	194	22.0	17.5	17.5	31 [illegible]	30 500	8.0	---
RT[d]	78	[illegible]	[illegible]	0	26 [illegible]	12 [illegible]	26.5	---
RT[e]				0	31 200	27 200	15.0	---
RT[f]			[illegible]	9.5	24 7[illegible]	22 [illegible]	13.0	---
RT[g]	78	[illegible]	[illegible]	9.5	31 100	29 500	11.5	---

TABLE 7. - Concluded

TENSILE PROPERTIES OF 6061 ALUMINUM ALLOY SHEET[a]

(Unstrained and prestrained conditions[b])

Test temperature, °K	Exposure or prestrain temperature, °K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Tensile properties			
					Ultimate strength, N/cm²	Yield strength, 0.2% offset, N/cm²	Elongation, percent in 5.08 cm	
							Total	Uniform
RT[f]	78	42.0	25.0	25.5	30 300	29 700	4.5	---
RT[g]			25.0	24.5	33 300	33 200	9.0	---
RT[f]			33.5	32.5	31 600	31 300	2.5	---
RT[g]	78	42.0	33.5	33.5	35 100	35 100	8.0	---
RT[d]	20	43.0	0	0	24 600	11 700	25.0	---
RT[e]			0	0	31 600	27 400	15.0	---
RT[f]			8.5	8.0	23 800	21 800	15.5	---
RT[g]			8.5	9.0	31 100	30 000	11.5	---
RT[f]			26.0	23.0	29 700	---	2.5	---
RT[g]			26.0	25.0	35 000	35 100	5.0	---
RT[f]			34.0	29.0	31 900	31 200	2.5	---
RT[g]	20	43.0	34.0	33.0	36 300	36 300	3.5	---

[a]Sheet, 0.229 cm. thick.

[b]All specimens were machined from annealed material. They were then solution treated (one hour at 800°K), water quenched, and immediately refrigerated and stored at 239°K.

[c]Condition: The specimens were removed from the refrigerator, exposed to the indicated temperature until the temperature of the specimens had stabilized at that temperature. They were tested within 15 minutes after thermal equilibrium had been achieved.

[d]Condition: The specimens were removed from the refrigerator, exposed to the indicated temperature, and were then naturally aged at room temperature for no less than seven days before being tested.

[e]Condition: Same as "d," except that after being naturally aged the specimens were precipitation heat treated (16 hours at 434°K) and then tested.

[f]Condition: The specimens were removed from the refrigerator, exposed to the indicated temperature and prestrained at that temperature within 15 minutes after thermal equilibrium was achieved, and then were naturally aged at room temperature for no less than 7 days before being tested.

[g]Condition: Same as "f," except that after being naturally aged the specimens were precipitation heat treated (16 hours at 434°K) and then tested.

TABLE 8

TENSILE PROPERTIES OF BERYLLIUM COPPER STRIP[a]
(Unstrained and prestrained conditions[b])

Test temperature, °F	Exposure or prestrain temperature, °F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Tensile properties: Ultimate strength, psi	Tensile properties: Yield strength, 0.2% offset, psi	Tensile properties: Elongation, percent in 2 in.: Total	Tensile properties: Elongation, percent in 2 in.: Uniform
RT[c]	---	---	---	---	---	---	---	50.0
-110[c]	---	---	---	---	77 400	41 100	65.5	55.0
-320[c]	---	---	---	---	99 300	55 600	70.5	65.0
-423[c]	---	---	---	---	120 800	65 400	68.5	61.0
RT[d]	RT	50.0	0	0	71 700	30 800	58.0	---
RT[e]			0	0	178 200	151 100	5.0	---
RT[f]			20.0	20.0	86 000	80 500	28.0	---
RT[g]			20.0	20.0	192 100	169 100	5.0	---
RT[f]			30.0	29.5	93 800	92 600	18.0	---
RT[g]			30.0	29.5	198 900	176 100	4.5	---
RT[f]			40.0	39.5	104 200	104 200	10.5	---
RT[g]	RT	50.0	40.0	39.5	200 700	180 600	2.5	---
RT[d]	-110	55.0	0	0	69 700	30 100	58.0	---
RT[e]			0	0	175 600	148 200	4.5	---
RT[f]			20.0	19.5	85 100	78 200	29.5	---
RT[g]			20.0	19.5	193 000	169 600	4.0	---
RT[f]			33.0	32.0	98 100	94 600	16.0	---
RT[g]			33.0	31.5	197 500	174 900	4.0	---
RT[f]			44.0	43.0	108 500	105 900	5.0	---
RT[g]	-110	55.0	44.0	44.5	202 300	182 900	3.0	---

TABLE 8. - Concluded

TENSILE PROPERTIES OF BERYLLIUM COPPER STRIP[a]

(Unstrained and prestrained conditions[b])

Test temperature, °F	Exposure or prestrain temperature, °F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Tensile properties			
					Ultimate strength, psi	Yield strength, 0.2% offset, psi	Elongation, percent in 2 in.	
							Total	Uniform
RT[d]	-320	65.0	0	0	71 000	29 700	55.5	---
RT[e]			0	0	174 900	147 700	4.5	---
RT[f]			20.0	20.0	91 100	84 000	22.5	---
RT[g]			20.0	19.5	191 700	170 200	3.5	---
RT[f]			39.0	39.5	117 900	112 200	3.0	---
RT[g]			39.0	39.5	201 500	181 800	3.5	---
RT[f]			52.0	53.0	133 800	126 900	2.0	---
RT[g]	-320	65.0	52.0	52.0	206 400	188 300	3.0	---
RT[d]	-423	61.0	0	0	70 900	31 400	57.0	---
RT[e]			0	0	179 200	148 400	6.0	---
RT[f]			20.0	18.0	90 300	79 000	26.5	---
RT[g]			20.0	18.0	191 200	169 700	5.5	---
RT[f]			36.0	33.5	108 200	100 900	13.5	---
RT[g]			36.0	33.0	200 700	180 100	5.0	---
RT[f]			48.0	48.0	129 100	117 900	2.5	---
RT[g]	-423	61.0	48.0	48.0	206 100	182 900	3.5	---

[a]Strip, 0.050 inch thick.

[b]All specimens were machined from annealed material.

[c]Condition: Annealed.

[d]Condition: Annealed and exposed to the indicated temperature.

[e]Condition: Same as "d" except that after exposure to temperature the specimens were aged (3 hours at 600°F.)

[f]Condition: Annealed and prestrained at the indicated temperature.

[g]Condition: Same as "f" except that after prestraining the specimens were aged for (3 hours at 600°F.)

TABLE 9

TENSILE PROPERTIES OF BERYLLIUM COPPER STRIP[a]

(Unstrained and prestrained conditions[b])

Test temperature, °K	Exposure or prestrain temperature, °K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Tensile properties: Ultimate strength, N/cm	Tensile properties: Yield strength, 0.2 offset, N/cm	Tensile properties: Elongation, percent in 5.08 cm: Total	Tensile properties: Elongation, percent in 5.08 cm: Uniform
RT[c]	---	---	---	---	---	---	---	50.0
194[c]	---	---	---	---	53 400	28 300	65.5	55.0
78[c]	---	---	---	---	68 500	38 300	70.5	65.0
20[c]	---	---	---	---	83 300	45 100	68.5	61.0
RT[d]	RT	50.0	0	0	49 400	21 200	58.0	---
RT[e]			0	0	122 900	104 200	5.0	---
RT[f]			20.0	20.0	59 300	55 500	28.0	---
RT[g]			20.0	20.0	132 500	116 600	5.0	---
RT[f]			30.0	29.5	64 700	63 800	18.0	---
RT[g]			30.0	29.5	137 100	121 400	4.5	---
RT[f]			40.0	39.5	71 800	71 800	10.5	---
RT[g]	RT	50.0	40.0	39.5	138 400	124 500	2.5	---
RT[d]	194	55.0	0	0	48 100	20 800	58.0	---
RT[e]			0	0	121 100	102 200	4.5	---
RT[f]			20.0	19.5	58 700	53 900	29.5	---
RT[g]			20.0	19.5	133 100	116 900	[illegible]	---
RT[f]			33.0	32.0	67 600	65 200	16.0	---
RT[g]			33.0	31.5	136 200	120 600	4.0	---
RT[f]			44.0	43.0	74 800	73 000	5.0	---
RT[g]	194	55.0	44.0	44.5	139 500	126 100	3.0	---

TABLE 9. - Concluded

TENSILE PROPERTIES OF BERYLLIUM COPPER STRIP[a]

(Unstrained and prestrained conditions[b])

Test temperature, °K	Exposure or prestrain temperature, °K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Tensile properties			
					Ultimate strength, (N/cm^2)	Yield strength, 0.2 offset, (N/cm^2)	Elongation, percent in 5.08 cm	
							Total	Uniform
RT[d]	78	65.0	0	0	49 000	20 500	55.5	---
RT[c]			0	0	120 600	101 500	4.5	---
RT[f]			20.0	20.0	62 800	57 900	22.5	---
RT[g]			20.0	19.5	132 200	117 400	3.5	---
RT[f]			39.0	39.5	81 300	77 400	3.0	---
RT[g]			39.0	39.5	138 900	125 400	3.5	---
RT[f]			52.0	53.0	92 300	87 500	2.0	---
RT[g]	78	65.0	52.0	52.0	142 300	129 800	3.0	---
RT[d]	20	61.0	0	0	48 900	21 700	57.0	---
RT[e]			0	0	123 600	102 300	6.0	---
RT[f]			20.0	18.0	62 300	54 500	26.5	---
RT[g]			20.0	18.0	131 800	117 000	5.5	---
RT[f]			36.0	33.5	74 600	69 600	13.5	---
RT[g]			36.0	33.0	138 400	124 200	5.0	---
RT[f]			48.0	48.0	89 000	81 500	2.5	---
RT[g]	20	61.0	48.0	48.0	142 100	126 100	3.5	---

[a]Strip, 0.127 cm. thick.

[b]All specimens were machined from annealed material.

[c]Condition: Annealed.

[d]Condition: Annealed and exposed to the indicated temperature.

[e]Condition: Same as "d" except after exposure to temperature the specimens were aged (3 hours at 589°K.)

[f]Condition: Annealed and prestrained at the indicated temperature.

[g]Condition: Same as "f" except after prestraining the specimens were aged (3 hours at 589°K.)

TABLE 10

TENSILE PROPERTIES OF L-605 COBALT ALLOY SHEET[a]
(unstrained and prestrained conditions[b])

Test temperature, °F	Exposure or prestrain temperature, °F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Tensile properties			
					Ultimate strength, psi	Yield strength, 0.2 offset, psi	Elongation, percent in 2 in.	
							Total	Uniform
RT[c]	---	---	---	---	150 400	70 400	59.0	55.0
-110[c]	---	---	---	---	171 500	---	50.0	48.0
-320[c]	---	---	---	---	210 300	---	43.5	41.0
-423[c]	---	---	---	---	237 500	---	38.5	36.5
RT[d]	RT	55.0	0	0	149 900	67 300	59.5	---
RT[e]			0	0	144 300	72 200	55.5	---
RT[f]			14.5	14.5	169 500	121 700	41.0	---
RT[g]			14.5	14.5	172 000	136 700	38.5	---
RT[f]			33.0	33.0	193 600	157 400	18.0	---
RT[g]			33.0	32.0	210 200	190 000	16.5	---
RT[f]			44.0	44.0	212 500	175 700	6.5	---
RT[g]	RT	55.0	44.0	44.5	247 400	215 300	4.5	---
RT[d]	-110	48.0	0	0	149 000	68 000	56.0	---
RT[e]			0	0	142 600	69 900	53.0	---
RT[f]			14.5	17.0	178 800	114 800	35.5	---
RT[g]			14.5	16.5	179 200	146 500	29.5	---
RT[f]			29.0	28.0	191 100	124 700	27.0	---
RT[g]			29.0	28.5	209 900	196 200	14.5	---
RT[f]			38.0	39.5	214 500	135 500	11.0	---
RT[g]	-110	48.0	38.0	38.5	241 800	221 900	4.5	---
RT[d]	-320	41.0	0	0	148 400	68 100	55.5	---
RT[e]			0	0	148 000	72 300	55.5	---
RT[f]			14.5	18.0	172 900	101 500	31.0	---
RT[g]	-320	41.0	14.5	15.0	172 300	145 200	27.5	---

TABLE 10. - Concluded

TENSILE PROPERTIES OF L-605 COBALT ALLOY SHEET[a]

Unstrained and prestrained conditions[b]

Test temperature, °F	Exposure or prestrain temperature, °F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Tensile properties			
					Ultimate strength, psi	Yield strength, 0.2% offset, psi	Elongation, percent in 2 in.	
							Total	Uniform
RT[f]	-320	41.0	24.0	23.0	204 200	119 000	26.5	---
RT[g]			24.0	23.5	199 200	177 000	19.0	---
RT[f,h]			32.0	34.0	202 600	158 300	10.0	---
RT[g]	-320	41.0	32.0	31.0	223 600	203 300	8.5	---
RT[d]	-423	36.5	0	0	143 400	67 800	54.0	---
RT[e]			0	0	143 100	70 100	54.5	---
RT[f]			14.5	9.5	166 100	99 900	47.0	---
RT[g]			14.5	13.0	175 600	138 300	34.5	---
RT[f]			22.0	21.0	180 300	124 100	36.0	---
RT[g]			22.0	20.5	194 100	166 300	23.5	---
RT[f]			29.0	26.0	196 000	122 500	23.0	---
RT[g]	-423	36.5	29.0	29.5	219 100	193 200	9.5	---

[a]Sheet, 0.068 inch thick.

[b]All specimens were machined from annealed material.

[c]Condition: Annealed.

[d]Condition: Annealed and exposed to the indicated temperature.

[e]Condition: Same as "d" except after exposure to temperature the specimens were aged (4 hours at 1100°F.)

[f]Condition: Annealed and prestrained at the indicated temperature.

[g]Condition: Same as "f" except after prestraining the specimens were aged (4 hours at 1100°F.)

[h]One specimen.

TABLE 11

TENSILE PROPERTIES OF L-605 COBALT ALLOY SHEET[a]
(Unstrained and prestrained conditions[b])

Test temperature, K	Exposure or prestrain temperature, K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Tensile properties: Ultimate strength, N/cm²	Tensile properties: Yield strength, 0.2 offset, N/cm²	Tensile properties: Elongation, percent in 5.08 cm: Total	Tensile properties: Elongation, percent in 5.08 cm: Uniform
RT[c]	---	---	---	---	103 700	48 500	59.0	55.0
194[c]	---	---	---	---	118 200	---	50.0	48.0
78[c]	---	---	---	---	145 000	---	43.5	41.0
20[c]	---	---	---	---	[illegible]	---	38.5	36.5
RT[d]	RT	55.0	0	0	103 400	46 400	59.5	---
RT[e]			0	0	99 500	49 800	55.5	---
RT[f]			14.5	14.5	116 900	83 900	41.0	---
RT[g]			14.5	13.5	118 600	[illegible]	38.5	---
RT[f]			33.0	33.0	133 500	108 500	18.0	---
RT[g]			33.0	32.0	144 900	[illegible]	16.5	---
RT[f]			[illegible]	44.0	146 500	[illegible]	[illegible]	---
RT[g]	RT	[illegible]	[illegible]	44.5	170 600	[illegible]	[illegible]	---
[illegible]	194	[illegible]	0	0	[illegible]	[illegible]	[illegible]	---
[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	---
[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	---
[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	29.5	---
RT[f]			[illegible]	28.0	[illegible]	[illegible]	27.0	---
RT[g]			29.0	28.5	144 700	135 [illegible]	14.5	---
RT[f]			[illegible]	39.5	[illegible] 900	93 400	11.0	---
RT[g]	194	[illegible]	[illegible]	38.5	166 700	155 [illegible]	4.5	---
RT[d]	78	[illegible]	0	0	[illegible]	[illegible]	55.5	---
RT[e]			[illegible]	[illegible]	[illegible]	[illegible]	55.5	---
RT[f]			[illegible]	[illegible]	[illegible]	[illegible]	41.0	---
RT[g]	78	[illegible]	14.5	15.0	[illegible]	[illegible]	[illegible]	---

TABLE 11. - Concluded

TENSILE PROPERTIES OF L-605 COBALT ALLOY SHEET[a]

Unstrained and prestrained conditions[b]

Test temperature, °K	Exposure or prestrain temperature, °K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Tensile properties			
					Ultimate strength, N/cm	Yield strength, 0.2% offset, N/cm	Elongation, percent in 5.08 cm	
							Total	Uniform
RT[f]	78	41.0	24.0	23.0	140 800	82 100	26.5	---
RT[g]			24.0	23.5	137 300	122 000	19.0	---
RT[f,h]			32.0	34.0	139 700	109 150	10.0	---
RT[g]	78	41.0	32.0	31.5	154 200	140 200	8.5	---
RT[d]	20	36.5	0	0	98 900	46 700	54.0	---
RT[e]			0	0	98 700	48 300	54.5	---
RT[f]			14.5	9.5	114 500	68 900	47.0	---
RT[g]			14.5	13.0	121 100	95 400	34.5	---
RT[f]			22.0	21.0	124 300	85 600	36.0	---
RT[g]			22.0	20.5	133 800	114 700	23.5	---
RT[f]			29.0	26.0	135 100	84 500	23.0	---
RT[g]	20	36.5	29.0	29.5	151 100	133 200	9.5	---

[a]Sheet, 0.173 cm. thick.

[b]All specimens were machined from annealed material.

[c]Condition: Annealed.

[d]Condition: Annealed and exposed to the indicated temperature.

[e]Condition: Same as "d" except after exposure to temperature the specimens were aged (4 hours at 866°K.)

[f]Condition: Annealed and prestrained at the indicated temperature.

[g]Condition: Same as "f" except after prestraining the specimens were aged (4 hours at 866°K.)

[h]One specimen.

TABLE 12

TENSILE PROPERTIES OF MP 35 N COBALT-NICKEL ALLOY SHEET[a]

(Unstrained and prestrained conditions[b])

Test temperature, °F	Exposure or prestrain temperature, °F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Tensile properties: Ultimate strength, psi	Yield strength, 0.2% offset, psi	Elongation, percent in 2 in.: Total	Uniform
RT[c]	---	---	---	---	123 700	---	63.0	55.0
-110[c]	---	---	---	---	146 700	61 000	77.0	70.0
-320[c]	---	---	---	---	178 500	81 100	77.0	70.0
-423[c]	---	---	---	---	211 000	---	78.5	75.0
RT[d]	RT	55.0	0	0	121 700	48 600	62.0	---
RT[e]			0	0	127 000	50 500	69.0	---
RT[f]			22.0	22.0	152 200	127 500	32.0	---
RT[g]			22.0	22.0	155 600	128 900	33.0	---
RT[f]			33.0	34.0	163 300	154 200	26.0	---
RT[g]			33.0	32.5	161 200	147 600	22.5	---
RT[f]			44.0	44.0	177 600	171 000	18.0	---
RT[g]	RT	55.0	44.0	44.0	187 400	187 400	8.5	---
RT[d]	-110	70.0	0	0	124 800	49 600	62.5	---
RT[e]			0	0	126 200	49 600	64.5	---
RT[f]			22.0	25.5	159 400	137 800	27.5	---
RT[g]			22.0	22.5	159 400	136 600	30.5	---
RT[f]			42.0	42.0	186 000	170 800	15.0	---
RT[g]			42.0	42.0	193 600	190 600	6.0	---
RT[f]			56.0	54.5	209 300	187 800	5.5	---
RT[g]	-110	70.0	56.0	53.5	218 200	217 200	3.0	---
RT[d]	-320	70.0	0	0	125 600	50 100	66.0	---
RT[e]			0	0	126 200	50 100	64.5	---
RT[f]			22.0	23.5	159 100	126 400	28.0	---
RT[g]	-320	70.0	22.0	22.5	163 400	147 600	27.5	---

TABLE 12. - Concluded

TENSILE PROPERTIES OF MP 35 N COBALT-NICKEL ALLOY SHEET[a]

(Unstrained and prestrained conditions[b])

Test temperature, °F	Exposure or prestrain temperature, °F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Tensile properties			
					Ultimate strength, psi	Yield strength, 0.2% offset, psi	Elongation, percent in 2 in.	
							Total	Uniform
RT[f]	-320	70.0	42.0	42.5	195 100	164 700	7.5	---
RT[g]			42.0	40.5	204 200	197 200	4.5	---
RT[f]			56.0	55.5	207 400	174 900	5.5	---
RT[g]	-320	70.0	56.0	56.5	241 300	224 400	2.0	---
RT[d]	-423	75.0	0	0	125 800	45 100	66.5	---
RT[e]			0	0	125 800	49 100	64.0	---
RT[f]			22.0	26.0	165 600	133 700	27.5	---
RT[g]			22.0	26.0	164 300	150 200	24.0	---
RT[f]			45.0	47.0	204 800	177 700	7.5	---
RT[g]			45.0	45.0	225 000	222 900	3.0	---
RT[f]			60.0	58.0	228 100	181 700	5.5	---
RT[g]	-423	75.0	60.0	60.0	260 100	258 900	2.0	---

[a]Sheet, 0.060 inch thick.

[b]All specimens were machined from annealed materal.

[c]Condition: Annealed.

[d]Condition: Annealed and exposed to the indicated temperature.

[e]Condition: Same as "d" except after exposure to temperature the specimens were aged (4 hours at 900°F.)

[f]Condition: Annealed and prestrained at the indicated temperature.

[g]Condition: Same as "f" except after prestraining the specimens were aged (4 hours at 900°F.)

TABLE 13

TENSILE PROPERTIES OF MP 35 N COBALT-NICKEL ALLOY SHEET[a]

(Unstrained and prestrained conditions[b])

Test temperature, K	Exposure or prestrain temperature, K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Tensile properties: Ultimate strength, N/cm	Tensile properties: Yield strength, 0.2% offset, N/cm	Tensile properties: Elongation, percent in 5.08 cm: Total	Tensile properties: Elongation, percent in 5.08 cm: Uniform
RT[c]	---	---	---	---	85 300	---	63.0	55.0
194[c]	---	---	---	---	101 100	42 100	77.0	70.0
78[c]	---	---	---	---	123 100	55 900	77.0	70.0
20[c]	---	---	---	---	145 500	---	78.5	75.0
RT[d]	RT	55.0	0	0	83 900	33 500	62.0	---
RT[e]			0	0	87 600	34 800	69.0	---
RT[f]			22.0	22.0	105 000	87 900	32.0	---
RT[g]			22.0	22.0	107 300	88 900	33.0	---
RT[f]			33.0	34.0	112 600	106 300	26.0	---
RT[g]			33.0	32.5	111 100	101 800	22.5	---
RT[f]			44.0	44.0	122 500	117 900	[illegible]	---
RT[g]	RT	55.0	44.0	44.0	129 200	129 200	[illegible]	---
RT[d]	194	70.0	0	0	86 600	34 200	[illegible]	---
RT[e]			0	0	87 600	34 200	64.5	---
RT[f]			22.0	22.5	[illegible]	[illegible]	[illegible]	---
RT[g]			22.0	[illegible]	114 900	[illegible]	[illegible]	---
RT[f]			42.0	42.5	128 200	117 500	15.0	---
RT[g]			42.0	42.0	133 500	131 400	6.0	---
RT[f]			56.0	54.5	144 300	129 500	5.5	---
RT[g]	194	70.0	56.0	53.5	150 400	149 800	5.0	---
RT[d]	78	70.0		0	86 600	34 500	66.0	---
RT[e]				0	87 000	34 500	64.5	---
RT[f]			22.0	23.5	109 700	87 200	26.0	---
RT[g]	78	70.0	22.0	22.5	112 700	101 800	27.5	---

TABLE 13. - Concluded

TENSILE PROPERTIES OF MP 35 N COBALT NICKEL ALLOY SHEET[a]

(Unstrained and prestrained conditions[b])

Test temperature, °K	Exposure or prestrain temperature, °K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Tensile properties			
					Ultimate strength, N/cm^2	Yield strength, 0.2 offset, N/cm^2	Elongation, percent in 5.08 cm	
							Total	Uniform
RT[f]	78	70.0	42.0	42.5	134 500	113 600	7.5	---
RT[g]			42.0	40.5	140 800	136 000	4.5	---
RT[f]			56.0	55.5	143 000	120 600	5.5	---
RT[g]	78	70.0	56.0	56.5	166 400	154 700	2.0	---
RT[d]	20	75.0	0	0	86 700	31 100	66.5	---
RT[e]			0	0	86 700	33 900	64.5	---
RT[f]			22.0	26.0	114 200	92 200	27.5	---
RT[g]			22.0	26.0	113 300	103 600	24.0	---
RT[f]			45.0	47.0	141 200	122 500	7.5	---
RT[g]			45.0	45.0	155 100	153 700	3.0	---
RT[f]			60.0	58.0	157 300	125 300	5.5	---
RT[g]	20	75.0	60.0	60.0	179 300	178 300	2.0	---

[a]Sheet, 0.152 cm thick.

[b]All specimens were machined from annealed material.

[c]Condition: Annealed.

[d]Condition: Annealed and exposed to the indicated temperature.

[e]Condition: Same as "d" except after exposure to temperature the specimens were aged (4 hours at 756°K.)

[f]Condition: Annealed and prestrained at the indicated temperature.

[g]Condition: Same as "f" except after prestraining the specimens were aged (4 hours at 756°K.)

TABLE 14

TENSILE PROPERTIES OF LA141A MAGNESIUM ALLOY SHEET[a]

(Unstrained and prestrained conditions[b])

Test temperature, °F	Exposure or prestrain temperature, °F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Poststrain treatment		Tensile properties			
					Temp, °F	Time at temp, hr	Ultimate strength, psi	Yield strength, 0.2 offset, psi	Elongation, percent in 2 in.	
									Total	Uniform
RT[c]	---	---	---	---	None	None	20 000	16 600	35.0	25.0
-110[c]	---	---	---	---	None	None	29 300	---	11.5	10.0
-320[c]	---	---	---	---	None	None	30 300	---	17.5	15.0
-423[c]	---	---	---	---	None	None	43 700	---	18.0	15.5
RT[d]	RT	25.0	0	0	None	None	21 300	18 300	22.0	---
RT[e]			4.0	4.0	None	None	22 300	20 500	19.5	---
RT[e]			15.0	15.0	None	None	20 400	18 900	18.0	---
RT[e]	RT	25.0	20.0	20.0	None	None	20 200	18 300	9.5	---
RT[f]	RT	25.0	4.0	4.0	150	1½	21 900	19 700	23.5	---
RT[g]					150	2	22 200	19 700	19.5	---
RT[h]					150	2½	22 100	19 800	17.5	---
RT[j]	RT	25.0	4.0	4.0	150	3	22 400	19 500	24.0	---
RT[d]	-110	10.0	0	0	None	None	20 700	19 000	21.5	---
RT[e]			4.0	3.5	None	None	22 700	21 100	18.0	---
RT[e]			6.0	5.5	None	None	22 700	20 900	19.5	---
RT[e]	-110	10.0	8.0	8.0	None	None	22 900	21 100	17.0	
RT[k]	-110	10.0	4.0	4.5	200	1	22 500	19 900	25.0	---
RT[m]				4.0	200	1½	22 600	20 400	19.5	---
RT[n]				3.5	200	2	22 500	20 200	20.0	---
RT[p]				4.0	200	2½	22 200	20 500	18.0	---
RT[q]	-110	10.0	4.0	4.0	200	3	22 300	20 500	14.0	---

TABLE 14. - Continued

TENSILE PROPERTIES OF LA141A MAGNESIUM ALLOY SHEET[a]

(Unstrained and prestrained conditions[b])

Test temperature, °F	Exposure or prestrain temperature, °F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Poststrain treatment		Tensile properties			
					Temp, °F	Time at temp, hr	Ultimate strength, psi	Yield strength, 0.2% offset, psi	Elongation, percent in 2 in.	
									Total	Uniform
RT[d]	-320	15.0	0	0	None	None	21 500	18 500	22.0	---
RT[e]			4.0	4.0	None	None	22 800	20 400	17.0	---
RT[e]			9.0	9.0	None	None	20 100	18 200	26.0	---
RT[e]	-320	15.0	12.0	11.5	None	None	20 800	17 700	19.0	---
RT[r]	-320	15.0	4.0	4.0	225	1	22 100	20 000	23.0	---
RT[s]					225	1½	21 800	19 200	19.5	---
RT[t]					225	2	22 600	19 900	18.5	---
RT[u]					225	2½	22 700	19 900	18.5	---
RT[v]	-320	15.0	4.0	4.0	225	3	22 000	19 300	15.2	---
RT[d]	-423	15.5	0	0	None	None	22 300	20 300	24.0	---
RT[e]			4.0	2.5	None	None	20 700	17 900	25.0	---
RT[e]			9.0	9.5	None	None	21 500	19 400	23.5	---
RT[e]	-423	15.5	12.0	13.0	None	None	21 900	19 300	20.5	---
RT[w]	-423	15.5	9.0	9.0	350	1	20 800	17 500	19.0	---
RT[x]					350	2	20 500	17 000	14.0	---
RT[y]					350	3	20 400	16 700	23.5	---
RT[z]					350	4	20 200	16 000	29.0	---
RT[aa]	-423	15.5	9.0	9.0	350	6	20 000	15 800	25.5	---
RT[ab]	-423	15.5	12.0	11.5	250	1	22 400	---	17.5	---
RT[ac]					250	1½	22 600	19 900	19.0	---
RT[ad]					250	2	22 800	19 500	19.0	---
RT[ae]					250	2½	22 300	19 000	17.0	---
RT[af]	-423	15.5	12.0	11.5	250	3	22 200	19 600	17.0	---

TABLE 14. - Concluded

TENSILE PROPERTIES OF LA141A MAGNESIUM ALLOY SHEET[a]
(Unstrained and prestrained conditions[b])

[a]Sheet, 0.090 inch thick.

[b]All specimens were machined from stabilized material (-T7 condition).

Condition: -T7.

Condition: -[illegible] and exposed to the indicated temperature.

Condition: -[illegible] and prestrained at the indicated temperature.

TABLE 15

TENSILE PROPERTIES OF LA141A MAGNESIUM ALLOY SHEET[a]

(Unstrained and prestrained conditions[b])

Test temperature, °K	Exposure or prestrain temperature, °K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Poststrain treatment		Tensile properties			
					Temp, °K	Time at temp, hr	Ultimate strength, N/cm	Yield strength, 0.2 offset, N/cm	Elongation, percent in 5.08 cm	
									Total	Uniform
RT[c]	---	---	---	---	None	None	13 800	11 400	35.0	25.0
194[c]	---	---	---	---	None	None	20 200	---	11.5	10.0
78[c]	---	---	---	---	None	None	20 900	---	17.5	15.0
20[c]	---	---	---	---	None	None	30 100	---	18.0	15.5
RT[d]	RT	25.0	0	0	None	None	14 700	12 600	22.0	---
RT[e]			4.0	4.0	None	None	15 400	14 100	19.5	---
RT[e]			15.0	15.0	None	None	14 100	13 000	18.0	---
RT[e]	RT	25.0	20.0	20.0	None	None	13 900	12 600	9.5	---
RT[f]	RT	25.0	4.0	4.0	339	1½	15 100	13 600	23.5	---
RT[g]					339	2	15 300	13 600	19.5	---
RT[h]					339	2½	15 200	13 700	17.5	---
RT[j]	RT	25.0	4.0	4.0	339	3	15 400	13 400	24.0	---
RT[d]	194	10.0	0	0	None	None	14 300	13 100	21.5	---
RT[e]			4.0	3.5	None	None	15 700	14 500	18.0	---
RT[e]			6.0	5.5	None	None	15 700	14 400	19.5	---
RT[e]	194	10.0	8.0	8.0	None	None	15 800	14 500	17.0	---
RT[k]	194	10.0	4.0	4.0	367	1	15 500	13 700	25.0	---
RT[m]					367	1½	15 600	14 100	19.5	---
RT[n]					367	2	15 500	13 900	20.0	---
RT[p]					367	2½	15 300	14 100	18.0	---
RT[q]	194	10.0	4.0	4.0	367	3	15 400	14 100	14.0	---

TABLE 15. - Continued

TENSILE PROPERTIES OF LA141A MAGNESIUM ALLOY SHEET[a]

(Unstrainted and prestrained conditions[b])

Test temperature, °K	Exposure or prestrain temperature, °K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Poststrain treatment		Tensile properties			
							Ultimate strength, N/cm	Yield strength, 0.2% offset, N/cm	Elongation, percent in 5.08 cm	
					Temp, °K	Time at temp, hr			Total	Uniform
RT[d]	78	15.0	0	0	None	None	14 800	12 800	22.0	---
RT[e]			4.0	4.0	None	None	15 700	14 100	17.0	---
RT[e]			9.0	9.0	None	None	13 900	12 500	26.0	---
RT[e]	78	15.0	12.0	11.5	None	None	14 300	12 200	19.0	---
RT[r]	78	15.0	4.0	4.0	381	1	15 200	13 800	23.0	---
RT[s]					381	1½	15 000	13 200	19.5	---
RT[t]					381	2	15 600	13 700	18.5	---
RT[u]					381	2½	15 700	13 700	18.5	---
RT[v]	78	15.0	4.0	4.0	381	3	15 200	13 300	15.2	---
RT[d]	20	15.5	0	0	None	None	15 400	14 000	24.0	---
RT[e]			4.0	2.5	None	None	14 300	12 300	25.0	---
RT[e]			9.0	9.5	None	None	14 800	13 400	23.5	---
RT[e]	20	15.5	12.0	13.0	None	None	15 100	13 300	20.5	---
					450	1				
RT[w]	20	15.5	9.0	9.0	450	2	14 300	12 100	19.0	---
RT[x]					450	3	14 100	11 700	14.0	---
RT[y]					450	4	14 100	11 500	23.5	---
RT[z]					450	6	13 900	11 000	29.0	---
RT[aa]	20	15.5	9.0	9.0			13 800	10 900	25.5	---
					395	1				
RT[ab]	20	15.5	12.0	11.5	395	1½	15 400	---	17.5	---
RT[ac]					395	2	15 600	13 700	19.0	---
RT[ad]					395	2½	15 700	13 400	19.0	---
RT[ae]					395	3	15 400	13 100	17.0	---
RT[af]	20	15.5	12.0	11.5			15 300	13 500	17.0	---

TABLE 15. - Concluded

TENSILE PROPERTIES OF LA141A MAGNESIUM ALLOY SHEET[a]

(Unstrained and prestrained conditions[b])

[a]Sheet, 0.229 cm thick.

[b]All specimens were machined from stabilized material (-T7 condition).

[c]Condition: -T7.

[d]Condition: -T7 and exposed to the indicated temperature.

[e]Condition: -T7 and prestrained at the indicated temperature.

TABLE 16

TENSILE PROPERTIES OF INCONEL 718 SHEET[a]
(Unstrained and prestrained conditions[b])

Test temperature, F	Exposure or prestrain temperature, F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Tensile properties: Ultimate strength, psi	Tensile properties: Yield strength, 0.2 offset, psi	Tensile properties: Elongation, percent in 2 in., Total	Tensile properties: Elongation, percent in 2 in., Uniform
RT[c]	---	---	---	---	120 300	56 500	55.5	49.0
-110[c]	---	---	---	---	136 400	65 300	60.0	55.0
-320[c]	---	---	---	---	160 300	80 700	66.0	60.0
-423[c]	---	---	---	---	183 900	94 100	61.5	57.0
RT[d]	RT	49.0	0	0	120 300	56 400	55.5	---
RT[e]			0	0	188 000	152 000	29.5	---
RT[f]			15.5	15.5	138 400	111 500	36.0	---
RT[g]			15.5	15.5	202 400	183 200	23.0	---
RT[h]			15.5	15.5	204 300	182 800	[illegible]	---
RT[f]			29.5	29.5	164 500	156 [illegible]	[illegible]	---
RT[g]			29.5	29.5	217 300	[illegible]	[illegible]	---
RT[h]			29.5	29.5	217 700	205 [illegible]	[illegible]	---
RT[f]			39.0	38.5	165 500	165 500	[illegible]	---
RT[g]			39.0	39.0	228 500	223 [illegible]	[illegible]	---
RT[h]	RT	[illegible]	39.0	[illegible]	233 100	229 [illegible]	[illegible]	---
RT[d]	[illegible]	[illegible]		[illegible]	116 700	[illegible]	[illegible]	---
RT[e]			0	0	187 800	132 [illegible]	[illegible]	---
RT[f]			15.5	15.5	138 200	111 200	34.5	---
RT[g]			15.5	15.5	202 700	182 900	27.5	---
RT[h]			15.5	15.5	205 000	183 100	23.5	---
RT[f]			33.0	31.5	157 600	152 200	14.0	---
RT[g]			33.0	32.0	221 500	215 600	16.0	---
RT[h]	-110	55.0	33.0	31.5	218 700	203 900	19.0	---

TABLE 16. - Continued

TENSILE PROPERTIES OF INCONEL 718 SHEET[a]

Unstrained and prestrained conditions[b]

Test temperature, F	Exposure or prestrain temperature, F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Tensile properties			
					Ultimate strength, psi	Yield strength, 0.2 offset, psi	Elongation, percent in 2 in.	
							Total	Uniform
RT[f]	-110	55.0	44.0	45.0	181 000	177 700	4.0	---
RT[g]			44.0	42.5	233 900	229 200	11.5	---
RT[h]	-110	55.0	44.0	45.0	230 200	221 300	14.0	---
RT[d]	-320	60.0	0	0	118 800	56 200	54.5	---
RT[e]			0	0	187 300	151 300	29.0	---
RT[f]			15.5	15.0	140 700	110 800	35.5	---
RT[g]			15.5	16.0	203 800	185 200	22.5	---
RT[h]			15.5	15.0	204 000	---	24.0	---
RT[f]			36.0	34.5	169 900	159 500	11.6	---
RT[g]			36.0	36.5	196 400	192 000	13.0	---
RT[h]			36.0	35.5	224 800	212 900	16.3	---
RT[f]			48.0	49.0	200 500	183 100	3.5	---
RT[g]			48.0	48.5	244 200	239 200	8.5	---
RT[h]	-320	60.0	48.0	48.0	234 600	221 100	14.0	---
RT[d]	-423	57.0	0	0	118 800	56 100	53.5	---
RT[e]			0	0	186 200	150 100	29.5	---
RT[f]			15.5	16.5	142 000	116 800	33.0	---
RT[g]			15.5	15.0	201 200	177 900	24.0	---
RT[h]			15.5	15.0	202 600	178 900	23.5	---
RT[f]			34.0	29.5	161 100	141 200	16.5	---
RT[g]			34.0	33.5	225 100	217 800	15.5	---
RT[h]			34.0	33.5	223 800	211 700	17.5	---
RT[f]			45.5	45.0	195 500	171 800	4.0	---
RT[g]			45.5	45.0	239 900	232 400	10.5	---
RT[h]	-423	57.0	45.5	45.0	233 800	225 900	14.8	

TABLE 16. - Concluded

TENSILE PROPERTIES OF INCONEL 718 SHEET[a]
(Unstrained and prestrained conditions[b])

Test temperature, °F	Exposure or prestrain temperature, °F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Tensile properties			
					Ultimate strength, psi	Yield strength, 0.2 offset, psi	Elongation, percent in 2 in.	
							Total	Uniform

[a]Sheet, 0.090 inch thick.

[b]All specimens were machined from annealed material.

[c]Condition: Annealed.

[d]Condition: Annealed and exposed to the indicated temperature.

[e]Condition: Same as "d" except after exposure to temperature the specimens were aged (16 hours at 1325°F.)

[f]Condition: Annealed and prestrained at the indicated temperature.

[g]Condition: Same as "f" except after prestraining the specimens were aged (16 hours at 1275°F.)

[h]Condition: Same as "f" except after prestraining the specimens were aged (16 hours at 1325°F.)

TABLE 17

TENSILE PROPERTIES OF INCONEL 718 SHEET[a]
(Unstrained and prestrained conditions[b])

Test temperature, °K	Exposure or prestrain temperature, °K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Tensile properties			
					Ultimate strength, N/cm^2	Yield strength, 0.2% offset, N/cm^2	Elongation, percent in 5.08 cm	
							Total	Uniform
RT[c]	---	---	---	---	82 900	39 000	55.5	49.0
194[c]	---	---	---	---	94 000	45 000	60.0	55.0
78[c]	---	---	---	---	110 500	55 600	66.0	60.0
20[c]	---	---	---	---	126 800	64 900	61.5	57.0
RT[d]	RT	49.0	0	0	82 900	38 900	55.5	---
RT[e]			0	0	129 600	104 800	29.5	---
RT[f]			15.5	15.5	95 400	76 900	36.0	---
RT[g]			15.5	15.2	139 600	126 300	23.0	---
RT[h]			15.5	15.5	140 900	126 000	24.0	---
RT[f]			29.5	29.5	113 400	107 600	22.5	---
RT[g]			29.5	29.5	149 800	144 600	16.5	---
RT[h]			29.5	29.5	150 100	140 300	19.0	---
RT[f]			39.0	38.5	114 100	114 100	15.5	---
RT[g]			39.0	39.0	157 600	154 200	13.5	---
RT[h]	RT	49.0	39.0	39.0	160 700	158 100	16.8	---
RT[d]	194	55.0	0	0	81 800	38 500	54.5	---
RT[e]			0	0	129 500	105 400	29.0	---
RT[f]			15.5	15.5	95 300	76 700	34.5	---
RT[g]			15.5	15.5	139 800	126 100	22.5	---
RT[h]			15.5	15.5	141 300	126 200	23.5	---
RT[f]			33.0	31.5	108 700	104 900	19.0	---
RT[g]			33.0	32.0	152 700	148 700	16.0	---
RT[h]	194	55.0	33.0	31.5	150 800	140 600	19.0	---

TABLE 17. - Continued

TENSILE PROPERTIES OF INCONEL 718 SHEET[a]

(Unstrained and prestrained conditions[b])

Test temperature, K	Exposure or prestrain temperature, K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Tensile properties			
					Ultimate strength, N/cm	Yield strength, 0.2 offset, N/cm	Elongation, percent in 5.08 cm	
							Total	Uniform
RT[f]	194	55.0	44.0	45.0	124 800	122 500	4.0	---
RT[g]			44.0	42.5	161 300	158 900	11.5	---
RT[h]	194	55.0	44.0	45.0	158 700	152 600	14.0	---
RT[d]	78	60.0	0	0	81 900	38 700	54.5	---
RT[e]			0	0	129 100	104 300	29.0	---
RT[f]			15.5	15.0	97 000	76 400	35.5	---
RT[g]			15.5	16.0	140 500	127 700	22.5	---
RT[h]			15.5	15.0	140 700	---	24.0	---
RT[f]			36.0	34.5	117 100	110 [illegible]	11.6	---
RT[g]			36.0	36.5	135 400	[illegible]	[illegible]	---
RT[h]			36.0	35.5	155 000	[illegible]	[illegible]	---
RT[f]			48.0	49.5	138 200	[illegible]	[illegible]	---
RT[g]			48.0	48.5	165 400	164 900	[illegible]	---
RT[h]	78	60.0	48.0	[illegible]	161 800	152 [illegible]	14.0	---
[illegible]	20	57.0	0	[illegible]	81 [illegible]	38 [illegible]	[illegible]	---
[illegible]			[illegible]		128 [illegible]	[illegible]	[illegible]	---
RT[f]			15.5	16.5	97 400	[illegible]	[illegible]	---
RT[g]			15.5	15.0	138 700	[illegible]	[illegible]	---
RT[h]			15.5	15.0	139 700	123 400	[illegible]	---
RT[f]			[illegible]	29.5	111 100	97 [illegible]	16.5	---
RT[g]			34.0	33.5	155 200	15[illegible] 200	13.3	---
RT[h]			[illegible]	33.5	154 300	146 000	17.5	---
RT[f]			45.5	45.0	134 800	118 300	[illegible]	---
RT[g]			45.5	45.0	165 400	163 200	13.5	---
RT[h]	20	57.0	45.5	45.0	161 200	155 [illegible]	14.[illegible]	---

TABLE 17. - Concluded

TENSILE PROPERTIES OF INCONEL 718 SHEET[a]
(Unstrained and prestrained conditions[b])

Test temperature, °K	Exposure or prestrain temperature, °K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Tensile properties			
					Ultimate strength, N/cm	Yield strength, 0.2% offset, N/cm	Elongation, percent in 5.08 cm	
							Total	Uniform

[a]Sheet, 0.229 cm thick.

[b]All specimens were machined from annealed material.

[c]Condition: Annealed.

[d]Condition: Annealed and exposed to the indicated temperature.

[e]Condition: Same as "d" except after exposure to temperature the specimens were aged (16 hours at 992°K.)

[f]Condition: Annealed and prestrained at the indicated temperature.

[g]Condition: Same as "f" except after prestraining the specimens were aged (16 hours at 964°K.)

[h]Condition: Same as "f" except after prestraining the specimens were aged (16 hours at 992°K.)

TABLE 18

TENSILE PROPERTIES OF NICKEL 440 STRIP[a]
(Unstrained and prestrained conditions[b])

Test temperature, F	Exposure or prestrain temperature, F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Tensile properties: Ultimate strength, psi	Tensile properties: Yield strength, 0.2 offset, psi	Tensile properties: Elongation, percent in 2 in.: Total	Tensile properties: Elongation, percent in 2 in.: Uniform
RT[c]	---	---	---	---	116 800	---	43.0	37.0
-110[c]	---	---	---	---	127 600	---	48.5	42.0
-320[c]	---	---	---	---	150 900	---	49.0	43.0
-423[c]	---	---	---	---	166 700	91 600	55.5	50.0
RT[d]	RT	37.0	0	0	118 900	50 200	42.1	---
RT[e]			0	0	249 700	174 800	14.0	---
RT[f]			15.0	14.5	136 500	116 900	26.5	---
RT[g]			15.0	15.0	274 000	204 000	14.5	---
RT[f]			22.0	22.0	146 100	139 000	18.2	---
RT[g]			22.0	22.0	282 300	219 200	11.0	---
RT[f]			29.5	29.5	152 200	151 200	12.5	---
RT[g]	RT	37.0	29.5	29.5	281 500	222 300	9.5	---
RT[d]	-110	42.0	0	0	116 900	49 400	42.0	---
RT[e]			0	0	248 500	177 300	13.0	---
RT[f]			15.0	17.0	137 800	121 500	24.0	---
RT[g]			15.0	15.0	272 600	203 100	13.5	---
RT[f]			25.0	27.0	149 600	147 200	14.0	---
RT[g]			25.0	25.0	282 700	221 900	11.0	---
RT[f]			33.5	33.0	156 900	156 100	8.0	---
RT[g]	-110	42.0	33.5	33.0	290 200	234 300	10.0	---
RT[d]	-320	43.0	0	0	119 000	50 300	42.0	---
RT[e]			0	0	249 100	177 200	13.6	---
RT[f]			15.0	15.5	134 200	113 700	24.5	---
RT[g]	-320	43.0	15.0	15.5	276 800	204 000	15.5	---

TABLE 18. - Concluded

TENSILE PROPERTIES OF NICKEL 440 STRIP[a]

Unstrained and prestrained conditions[b]

Test temperature, °F	Exposure or prestrain temperature, °F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Tensile properties			
					Ultimate strength, psi	Yield strength, 0.2% offset, psi	Elongation, percent in 2 in.	
							Total	Uniform
RT[f]	-320	43.0	26.0	25.0	148 100	144 200	15.0	---
RT[g]			26.0	26.0	286 700	226 100	11.0	---
RT[f]			34.5	34.0	166 600	166 500	5.0	---
RT[g]	-320	43.0	34.5	34.0	294 700	238 600	10.0	---
RT[d]	-423	50.0	0	0	118 700	50 700	41.0	---
RT[e]			0	0	250 800	177 900	14.7	---
RT[f]			15.0	15.0	135 100	113 800	23.5	---
RT[g]			15.0	15.0	271 200	194 900	14.0	---
RT[f]			30.0	34.0	165 200	161 200	8.0	---
RT[g]			30.0	32.0	292 600	231 200	10.5	---
RT[f]			40.0	45.0	181 700	177 800	3.5	---
RT[g]	-423	50.0	40.0	42.5	302 400	252 400	9.5	---

[a]Strip, 0.062 inch thick.

[b]All specimens were machined from annealed material.

[c]Condition: Annealed.

[d]Condition: Annealed and exposed to the indicated temperature.

[e]Condition: Same as "d" except after exposure to temperature the specimens were aged (1.5 hours at 970°F).

[f]Condition: Annealed and prestrained at the indicated temperature.

[e]Condition: Same as "f" except after prestraining the specimens were aged (1.5 hours at 930°F).

TABLE 19

TENSILE PROPERTIES OF NICKEL 440 STRIP[a]

(Unstrained and prestrained conditions[b])

Test temperature, K	Exposure or prestrain temperature, K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Tensile properties			
					Ultimate strength, N/cm	Yield strength, 0.2 offset, N/cm	Elongation, percent in 5.08 cm	
							Total	Uniform
RT[c]	---	---	---	---	80 500	---	43.0	37.0
194[c]	---	---	---	---	88 000	---	48.5	42.0
78[c]	---	---	---	---	104 000	---	49.6	43.0
20[c]	---	---	---	---	114 900	63 200	55.5	50.0
RT[d]	RT	37.0	0	0	82 000	34 600	42.1	---
RT[e]			0	0	172 200	120 500	14.0	---
RT[f]			15.0	14.5	94 100	80 600	26.5	---
RT[g]			15.0	15.0	188 900	140 700	14.5	---
RT[f]			22.0	22.0	100 700	95 800	18.2	---
RT[g]			22.0	22.0	194 600	151 100	11.0	---
RT[f]			29.5	29.5	104 900	104 300	[illegible]	---
RT[g]	RT	37.0	29.5	29.5	194 100	155 300	[illegible]	---
RT[d]	194	[illegible]	0	0	80 600	[illegible]	[illegible]	---
RT[e]			0	0	172 200	[illegible]	[illegible]	---
RT[f]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	---
RT[g]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	---
RT[f]			25.0	[illegible]	[illegible]	[illegible]	[illegible]	---
RT[g]			25.0	[illegible]	194 900	[illegible]	11.0	---
RT[f]			33.5	33.0	108 200	167 600	[illegible]	---
RT[g]	194	42.0	33.5	33.0	200 100	161 500	10.0	---
RT[d]	78	43.0	0	0	82 100	[illegible]	[illegible]	---
RT[e]			[illegible]	0	171 800	122 200	[illegible]	---
RT[f]			15.0	15.5	92 500	78 400	24.5	---
RT[g]	78	43.0	15.3	15.5	190 900	140 700	15.5	---

TABLE 19. - Concluded

TENSILE PROPERTIES OF NICKEL 440 STRIP[a]
(Unstrained and prestrained conditions[b])

Test temperature, °K	Exposure or prestrain temperature, °K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Tensile properties: Ultimate strength, N/cm²	Tensile properties: Yield strength, 0.2% offset, N/cm²	Elongation, percent in 5.08 cm: Total	Elongation, percent in 5.08 cm: Uniform
RT[f]	78	43.0	26.0	25.0	102 100	99 400	15.0	---
RT[g]			26.0	26.0	197 700	155 900	11.0	---
RT[f]			34.5	34.0	114 900	114 800	5.0	---
RT[g]	78	43.0	34.5	34.0	203 200	164 500	10.0	---
RT[d]	20	50.0	0	0	81 800	35 000	41.0	---
RT[e]			0	0	172 900	122 700	14.7	---
RT[f]			15.0	15.0	93 200	78 500	23.5	---
RT[g]			15.0	15.0	187 000	134 400	14.0	---
RT[f]			30.0	34.0	113 900	111 100	8.0	---
RT[g]			30.0	32.0	201 700	159 400	10.5	---
RT[f]			40.0	45.0	125 300	122 600	3.5	---
RT[g]	20	50.0	40.0	42.5	208 500	174 900	9.5	---

[a]Strip, 0.157 cm thick.

[b]All specimens were machined from annealed material.

[c]Condition: Annealed.

[d]Condition: Annealed and exposed to the indicated temperature.

[e]Condition: Same as "d" except after exposure to temperature the specimens were aged (1.5 hours at 795°K).

[f]Condition: Annealed and prestrained at the indicated temperature.

[g]Condition: Same as "f" except after prestraining the specimens were aged (1.5 hours at 773°K).

TABLE 20

TENSILE PROPERTIES OF A-286 CORROSION RESISTANT STEEL[a]

(Unstrained and prestrained conditions[b])

Test temperature, °F	Exposure or prestrain temperature, °F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Tensile properties			
					Ultimate strength, psi	Yield strength, 0.2 offset, psi	Elongation, percent in 2 in.	
							Total	Uniform
RT[c]	---	---	---	---	---	---	41	36.0
-110[c]	---	---	---	---	107 100	52 600	48.5	44.0
-320[c]	---	---	---	---	144 100	74 900	77.0	72.5
-423[c]	---	---	---	---	177 100	90 400	70.0	65.0
RT[d]	RT	36.0	0	0	93 400	45 700	40.5	---
RT[e]			0	0	154 400	111 600	23.5	---
RT[f]			14.5	14.5	100 500	88 300	23.5	---
RT[g]			14.5	14.0	155 600	132 400	20.0	---
RT[h]			14.5	14.5	170 500	147 300	16.0	---
RT[f]			21.5	21.5	111 600	107 900	17.0	---
RT[g]			21.5	21.5	165 700	151 300	13.0	---
RT[h]			21.5	21.0	178 000	163 000	13.5	---
RT[f]			29.0	29.5	120 200	120 200	12.0	---
RT[g]			29.0	29.0	173 300	163 500	11.5	---
RT[h]	RT	36.0	29.0	29.5	184 100	173 800	11.5	---
RT[d]	-110	44.0	0	0	92 200	45 600	39.5	---
RT[e]			0	0	154 300	112 000	23.5	---
RT[f]			14.5	14.5	105 600	95 900	24.0	---
RT[g]			14.5	14.0	154 000	132 200	20.0	---
RT[h]	-110	44.0	14.5	18.5	174 100	154 600	15.0	---

TABLE 20. - Continued

TENSILE PROPERTIES OF A-286 CORROSION RESISTANT STEEL SHEET[a]
(Unstrained and prestrained conditions[b])

Test temperature, °F	Exposure or prestrain temperature, °F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Tensile properties			
					Ultimate strength, psi	Yield strength, 0.2% offset, psi	Elongation, percent in 2 in.	
							Total	Uniform
RT[f]	-110	44.0	26.0	25.5	116 500	113 200	13.0	---
RT[g]			26.0	25.5	173 500	164 000	12.0	---
RT[h]			26.0	24.0	181 800	168 700	12.5	---
RT[f]			35.0	36.0	132 400	128 700	4.5	---
RT[g]			35.0	33.5	179 800	173 400	10.0	---
RT[h]	-110	44.0	35.0	33.0	186 600	173 900	11.0	---
RT[d]	-320	72.5	0	0	92 300	45 900	38.5	---
RT[e]			0	0	154 000	111 100	23.5	---
RT[f]			14.5	15.5	107 900	93 400	21.5	---
RT[g]			14.5	15.0	157 100	138 600	18.0	---
RT[h]			14.5	17.0	171 100	147 700	17.5	---
RT[f]			43.5	45.5	149 000	130 000	4.5	---
RT[g]			43.5	43.5	199 000	195 900	6.5	---
RT[h]			43.5	44.0	192 800	176 400	12.5	---
RT[f]			58.0	57.5	165 200	145 600	3.0	---
RT[g]			58.0	57.5	219 200	216 600	5.5	---
RT[h]	-320	72.5	58.0	57.5	200 300	184 400	8.5	---
RT[d]	-423	65.0	0	0	92 000	46 000	40.0	---
RT[e]			0	0	154 000	111 300	24.0	---
RT[f]			14.5	16.5	111 300	94 600	21.0	---
RT[g]			14.5	16.5	164 500	147 000	18.0	---
RT[h]	-423	65.0	14.5	16.5	173 900	147 600	18.0	---

TABLE 20. - Concluded

TENSILE PROPERTIES OF A-286 CORROSION RESISTANT STEEL SHEET[a]

(Unstrained and prestrained conditions[b])

Test temperature, °F	Exposure or prestrain temperature, °F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Tensile properties			
					Ultimate strength, psi	Yield strength, 0.2 offset, psi	Elongation, percent in 2 in.	
							Total	Uniform
RT[f]	-423	65.0	39.0	40.5	153 800	125 600	6.0	---
RT[g]	↕	↕	39.0	40.5	204 100	199 800	5.5	---
RT[h]	↕	↕	39.0	40.5	193 900	174 000	11.5	---
RT[f]	↕	↕	52.0	49.5	165 900	134 000	5.0	---
RT[g]	↕	↕	52.0	49.5	216 700	216 500	4.5	---
RT[h]	-423	65.0	52.0	49.5	198 800	178 100	6.5	---

[a]Sheet, 0.055 inch thick.

[b]All specimens were machined from annealed material.

[c]Condition: Annealed.

[d]Condition: Annealed and exposed to the indicated temperature.

[e]Condition: Same as "d" except after exposure to temperature the specimens were aged (16 hours at 1325°F.)

[f]Condition: Annealed and prestrained at the indicated temperature.

[g]Condition: Same as "f" except after prestraining the specimens were aged (16 hours at 1150°F.)

[h]Condition: Same as "f" except after prestraining the specimens were aged (16 hours at 1250°F.)

TABLE 21

TENSILE PROPERTIES OF A-286 CORROSION RESISTANT STEEL SHEET[a]
(Unstrained and prestrained conditions[b])

Test temperature, °K	Exposure or prestrain temperature, °K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Tensile properties			
					Ultimate strength, N/cm	Yield strength, 0.2% offset, N/cm	Elongation, percent in 5.08 cm	
							Total	Uniform
RT[c]	---	---	---	---	---	---	41.0	36.0
194[c]	---	---	---	---	73 800	36 300	48.5	44.0
78[c]	---	---	---	---	99 400	51 600	77.0	72.5
20[c]	---	---	---	---	122 100	62 300	70.0	65.0
RT[d]	RT	36.0	0	0	64 400	31 500	40.5	---
RT[e]			0	0	106 500	76 900	23.5	---
RT[f]			14.5	14.5	69 300	60 900	23.5	---
RT[g]			14.5	14.0	107 300	91 300	20.0	---
RT[h]			14.5	14.5	117 600	101 600	16.0	---
RT[f]			21.5	21.5	76 900	74 400	17.0	---
RT[g]			21.5	21.5	114 300	104 300	13.0	---
RT[h]			21.5	21.0	122 700	112 400	13.5	---
RT[f]			29.0	29.5	82 900	82 900	12.0	---
RT[g]			29.0	29.0	119 500	112 700	11.5	---
RT[h]	RT	36.0	29.0	29.5	126 900	119 800	11.5	---
RT[d]	194	44.0	0	0	63 600	31 400	39.5	---
RT[e]			0	0	106 500	77 200	23.5	---
RT[f]			14.5	14.5	72 800	66 100	24.0	---
RT[g]			14.5	14.0	106 200	91 200	20.0	---
RT[h]			14.5	18.5	120 000	106 600	15.0	---
RT[f]			26.0	25.5	80 300	78 100	13.0	---
RT[g]			26.0	25.5	119 600	113 100	12.0	---
RT[h]	194	44.0	26.0	24.0	125 400	116 300	12.5	---

TABLE 21. - Continued

TENSILE PROPERTIES OF A-286 CORROSION RESISTANT STEEL SHEET[a]
(Unstrained and prestrained conditions[b])

Test temperature, K	Exposure or prestrain temperature, K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Tensile properties			
					Ultimate strength, N/cm²	Yield strength, 0.2% offset, N/cm²	Elongation, percent in 5.08 cm	
							Total	Uniform
RT[f]	194	44.0	35.0	36.0	91 300	88 700	4.5	---
RT[g]			35.0	33.5	124 000	119 600	10.0	---
RT[h]	194	44.0	35.0	33.0	128 700	119 900	11.0	---
RT[d]	78	72.5	0	0	63 600	31 600	38.5	---
RT[e]			0	0	106 200	76 600	23.5	---
RT[f]			14.5	15.5	74 400	64 400	21.5	---
RT[g]			14.5	15.0	108 300	95 600	18.0	---
RT[h]			14.5	17.0	118 000	101 800	17.5	---
RT[f]			43.5	45.5	102 700	89 600	4.5	---
RT[g]			43.5	43.5	137 200	135 100	6.5	---
RT[h]			43.5	44.0	132 900	121 600	12.5	---
RT[f]			58.0	57.5	113 900	100 400	3.0	---
RT[g]			58.0	57.5	151 100	149 300	5.5	---
RT[h]	78	72.5	58.0	57.5	138 100	127 100	8.5	---
RT[d]	20	65.0	0	0	63 400	31 700	40.0	---
RT[e]			0	0	106 200	76 700	24.0	---
RT[f]			14.5	16.5	76 700	65 200	21.0	---
RT[g]			14.5	16.5	113 400	101 400	18.0	---
RT[h]			14.5	16.5	119 900	101 800	18.0	---
RT[f]			39.0	40.5	106 000	86 600	6.0	---
RT[g]			39.0	40.5	140 700	137 800	5.5	---
RT[h]			39.0	40.5	133 700	120 000	11.5	---
RT[f]			52.0	49.5	114 400	92 400	5.0	---
RT[g]			52.0	49.5	149 400	145 300	4.5	---
RT[h]	20	65.0	52.0	49.5	137 100	122 800	6.5	---

TABLE 21. - Concluded

TENSILE PROPERTIES OF A-286 CORROSION RESISTANT STEEL SHEET[a]

Unstrained and prestrained conditions[b]

Test temperature, °K	Exposure or prestrain temperature, °K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Tensile properties			
					Ultimate strength, N/cm²	Yield strength, 0.2% offset, N/cm²	Elongation, percent in 5.08 cm	
							Total	Uniform

[a]Sheet, 0.140 cm, thick.

[b]All specimens were machined from annealed material.

[c]Condition: Annealed.

[d]Condition: Annealed and exposed to the indicated temperature.

[e]Condition: Same as "d" except after exposure to temperature the specimens were aged (16 hours at 992°K.)

[f]Condition: Annealed and prestrained at the indicated temperature.

[g]Condition: Same as "f" except after prestraining the specimens were aged (16 hours at 894°K.)

[h]Condition: Same as "f" except after prestraining the specimens were aged (16 hours at 951°K.)

TABLE 22

TENSILE PROPERTIES OF PH 14-8 Mo CORROSION RESISTANT STEEL SHEET[a]

(Unstrained and prestrained conditions[b])

Test temperature, F	Exposure or prestrain temperature, F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Tensile properties			
					Ultimate strength, psi	Yield strength, 0.2 offset, psi	Elongation, percent in 2 in.	
							Total	Uniform
RT[c]	---	---	---	---	135 400	55 700	26.0	21.0
-110[c]	---	---	---	---	185 900	66 500	17.0	13.0
-320[c]	---	---	---	---	289 200	80 500	22.5	18.5
-423[c]	---	---	---	---	324 400	---	17.0	15.0
RT[d]	RT	21.0	0	0	130 600	55 000	26.5	---
RT[e]			0	0	127 800	54 700	28.0	---
RT[f]			5.5	5.5	141 400	71 000	19.5	---
RT[g]			5.5	5.5	139 900	87 400	27.5	---
RT[f]			13.5	13.0	150 800	135 200	[illegible]	---
RT[g]			13.5	13.5	199 700	197 600	10.0	---
RT[f]			17.5	17.5	167 000	167 000	5.0	---
RT[g]	RT	21.0	17.5	17.5	231 400	231 100	[illegible]	---
RT[d]	-110	13.0	0	0	130 700	55 000	27.5	---
RT[e]			0	0	129 400	55 400	28.0	---
RT[f]			[illegible]	5.5	[illegible]	[illegible]	[illegible]	---
RT[g]			[illegible]	5.5	[illegible]	[illegible]	[illegible]	---
RT[f]			[illegible]	7.0	182 400	[illegible]	7.5	---
RT[g]			8.0	7.0	249 700	247 500	7.0	---
RT[f]			10.5	10.5	195 400	194 700	4.0	---
RT[g]	-110	13.0	10.5	10.0	271 700	271 700	6.5	---
RT[d]	-320	18.5	0	0	130 300	55 600	27.0	---
RT[e]			0	0	130 300	54 000	27.5	---
RT[f]			5.5	6.0	217 200	110 900	9.5	---
RT[g]	-320	18.5	5.5	6.0	250 500	181 800	6.5	---

TABLE 22. - Concluded

TENSILE PROPERTIES OF PH 14-8 Mo CORROSION RESISTANT STEEL SHEET[a]

(Unstrained and prestrained conditions[b])

Test temperature, °F	Exposure or prestrain temperature, °F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Tensile properties			
					Ultimate strength, psi	Yield strength, 0.2% offset, psi	Elongation, percent in 2 in.	
							Total	Uniform
RT[f]	-320	18.5	11.0	10.0	228 300	214 900	8.0	---
RT[g]			11.0	10.5	305 400	298 700	6.0	---
RT[f]			14.5	15.0	250 500	241 800	3.5	---
RT[g]	-320	18.5	14.5	14.5	329 400	326 800	5.0	---
RT[d]	-423	15.0	0	0	127 000	54 000	26.5	---
RT[e]			0	0	130 400	54 100	27.5	---
RT[f]			5.5	6.5	218 500	121 200	9.0	---
RT[g]			5.5	4.5	164 900	76 600	8.0	---
RT[f]			9.0	7.0	214 600	110 600	10.0	---
RT[g]			9.0	8.0	260 000	217 900	10.0	---
RT[f]			12.0	9.8	225 600	189 500	8.0	---
RT[g]	-423	15.0	12.0	10.0	284 300	261 200	7.0	---

[a]Sheet, 0.070 inch thick.

[b]All specimens were machined from annealed material.

[c]Condition: Annealed.

[d]Condition: Annealed and exposed to the indicated temperature.

[e]Condition: Same as "d" except after exposure to temperature the specimens were aged (1 hour at 900°F.)

[f]Condition: Annealed and prestrained at the indicated temperature.

[g]Condition: Same as "f" except after prestraining the specimens were aged (1 hour at 900°F.)

TABLE 23

TENSILE PROPERTIES OF PH 14-8 Mo CORROSION RESISTANT STEEL SHEET[a]

(Unstrained and prestrained conditions[b])

Test temperature, °K	Exposure or prestrain temperature, °K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Tensile properties: Ultimate strength, N/cm^2	Tensile properties: Yield strength, 0.2 offset, N/cm^2	Elongation, percent in 5.08 cm: Total	Elongation, percent in 5.08 cm: Uniform
RT[c]	---	---	---	---	93 400	38 400	26.0	21.0
194[c]	---	---	---	---	128 200	45 900	17.0	13.0
78[c]	---	---	---	---	199 400	55 500	22.5	18.5
20[c]	---	---	---	---	223 700	---	17.0	15.0
RT[d]	RT	21.0	0	0	90 000	37 900	26.5	---
RT[e]			0	0	88 100	37 700	28.0	---
RT[f]			5.5	5.5	97 500	49 000	19.5	---
RT[g]			5.5	5.5	96 500	60 300	27.5	---
RT[f]			13.5	13.0	104 000	93 200	12.0	---
RT[g]			13.5	13.5	137 700	136 200	10.0	---
RT[f]			17.5	17.5	115 100	115 100	5.0	---
RT[g]	RT	21.0	17.5	17.5	159 600	159 300	4.0	---
RT[d]	194	13.0	0	0	90 100	37 900	27.5	---
RT[e]			0	0	89 200	38 200	28.0	---
RT[f]			5.5	5.5	121 100	75 200	10.5	---
RT[g]			5.5	5.5	148 100	134 700	7.0	---
RT[f]			8.0	7.0	125 800	116 500	7.5	---
RT[g]			8.0	7.0	172 200	170 700	7.0	---
RT[f]			10.5	10.5	134 700	134 200	4.0	---
RT[g]	194	13.0	10.5	10.0	187 300	187 300	6.5	---
RT[d]	78	18.5	0	0	89 800	38 300	27.0	---
RT[e]			0	0	89 800	37 200	27.5	---
RT[f]			5.5	6.0	149 800	76 500	9.5	---
RT[g]	78	18.5	5.5	6.0	172 700	125 400	6.5	---

TABLE 23. - Concluded

TENSILE PROPERTIES OF PH 14-8 Mo CORROSION RESISTANT STEEL SHEET[a]

(Unstrained and prestrained conditions[b])

Test temperature, °K	Exposure or prestrain temperature, °K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Tensile properties: Ultimate strength, N/cm²	Tensile properties: Yield strength, 0.2% offset, N/cm²	Tensile properties: Elongation, percent in 5.08 cm: Total	Tensile properties: Elongation, percent in 5.08 cm: Uniform
RT[f]	78	18.5	11.0	10.0	157 400	148 200	8.0	---
RT[g]			11.0	10.5	210 600	206 000	6.0	---
RT[f]			14.5	15.0	172 700	166 700	3.5	---
RT[g]	78	18.5	14.5	14.5	227 100	225 300	5.0	---
RT[d]	20	15.0	0	0	87 600	37 200	26.5	---
RT[e]			0	0	89 900	37 300	27.5	---
RT[f]			5.5	6.5	150 700	83 600	9.0	---
RT[g]			5.5	4.5	113 700	52 800	8.0	---
RT[f]			9.0	7.0	148 000	76 300	10.0	---
RT[g]			9.0	8.0	179 300	150 200	10.0	---
RT[f]			12.0	9.8	155 600	130 700	8.0	---
RT[g]	20	15.0	12.0	10.0	196 000	180 100	7.0	---

[a]Sheet, 0.178 cm thick.

[b]All specimens were machined from annealed material.

[c]Condition: Annealed.

[d]Condition: Annealed and exposed to the indicated temperature.

[e]Condition: Same as "d" except after exposure to temperature the specimens were aged (1 hour at 756°K.)

[f]Condition: Annealed and prestrained at the indicated temperature.

[g]Condition: Same as "f" except after prestraining the specimens were aged (1 hour at 756°K.)

TABLE 24

TENSILE PROPERTIES OF TRIP STEEL STRIP[a]
(Unstrained and prestrained conditions[b])

Test temperature, °F	Exposure or prestrain temperature, °F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Tensile properties: Ultimate strength, psi	Tensile properties: Yield strength, 0.2 offset, psi	Tensile properties: Elongation, percent in 2 in.: Total	Tensile properties: Elongation, percent in 2 in.: Uniform
RT[c]	---	---	---	---	247 800	228 400	20.5	20.0
-110[c]	---	---	---	---	311 300	---	22.0	10.5
-320[c]	---	---	---	---	255 100	---	9.0	10.0
-423[c]	---	---	---	---	---	---	0	0
RT[d]	RT	20.0	0	0	247 800	228 400	20.5	---
RT[e]			0	0	239 900	225 800	25.0	---
RT[f]			18.0	18.5	309 000	274 000	9.5	---
RT[g]	RT	20.0	18.0	18.0	304 500	280 500	5.0	---
RT[d]	-110	10.5	0	0	244 800	219 [illegible]	27.5	---
RT[e]			0	0	239 600	215 600	21.5	---
RT[f]			9.0	9.0	305 800	264 300	[illegible]	---
RT[g]	-110	10.5	9.0	8.5	309 400	307 900	7.0	---
RT[d]	-320	10.0	0	0	252 500	226 700	22.0	---
RT[e]			0	0	241 200	228 200	[illegible]	---
RT[f]			8.0	8.[illegible]	315 400	269 [illegible]	[illegible]	---
RT[g]	-320	10.0	8.0	8.5	279 500	261 800	2.0	---
RT[d]	-423	0	0	0	242 700	229 400	24.0	---

TABLE 24. - Concluded

TENSILE PROPERTIES OF TRIP STEEL STRIP[a]

Unstrained and prestrained conditions[b]

Test temperature, °F	Exposure or prestrain temperature, °F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Tensile properties			
					Ultimate strength, psi	Yield strength, 0.2 offset, psi	Elongation, percent in 2 in.	
							Total	Uniform

[a]Strip, 0.110 inch thick.

[b]All specimens were machined from TRIP processed material.

[c]Condition: TRIP processed.

[d]Condition: TRIP processed and exposed to the indicated temperature.

[e]Condition: Same as "d" except after exposure to temperature the specimens were aged (1/2 hour at 750°F).

[f]Condition: TRIP processed and prestrained at the indicated temperature.

[g]Condition: Same as "f" except after prestraining the specimens were aged (1/2 hour at 750°F).

TABLE 25

TENSILE PROPERTIES OF TRIP STEEL STRIP[a]
(Unstrained and prestrained conditions[b])

Test temperature, °K	Exposure or prestrain temperature, °K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Tensile properties			
					Ultimate strength, N/cm	Yield strength, 0.2% offset, N/cm	Elongation, percent in 5.08 cm	
							Total	Uniform
RT[c]	---	---	---	---	170 900	157 500	20.5	20.0
194[c]	---	---	---	---	214 600	---	22.0	10.5
78[c]	---	---	---	---	175 900	---	9.0	10.0
20[c]	---	---	---	---	---	---	0	0
RT[d]	RT	20.0	0	0	170 900	157 500	20.5	---
RT[e]			0	0	165 400	155 700	25.0	---
RT[f]			18.0	18.5	213 100	188 900	9.5	---
RT[g]	RT	20.0	18.0	18.0	210 000	193 400	5.0	---
RT[d]	194	10.5	0	0	168 800	151 100	27.5	---
RT[e]			0	0	165 200	148 700	21.5	---
RT[f]			9.0	9.0	210 800	182 200	4.0	---
RT[g]	194	10.5	9.0	8.5	213 300	212 300	7.0	---
RT[d]	78	10.0	0	0	174 100	156 300	23.0	---
RT[e]			0	0	166 300	157 300	23.5	---
RT[f]			8.0	8.0	219 500	185 500	4.0	---
RT[g]	78	10.0	8.0	8.5	192 700	180 500	2.0	---
RT[d]	20	0	0	0	167 300	158 200	24.0	---

TABLE 25. - Concluded

TENSILE PROPERTIES OF TRIP STEEL STRIP[a]
(Unstrained and prestrained conditions[b])

Test temperature, °K	Exposure or prestrain temperature, °K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Tensile properties			
					Ultimate strength, N/cm^2	Yield strength, 0.2% offset, N/cm^2	Elongation, percent in 5.08 cm	
							Total	Uniform

[a]Strip, 0.279 cm. thick.

[b]All specimens were machined from TRIP processed material.

[c]Condition: TRIP processed.

[d]Condition: TRIP processed and exposed to the indicated temperature.

[e]Condition: Same as "d" except after exposure to temperature the specimens were aged (1/2 hour at 673°K).

[f]Condition: TRIP processed and prestrained at the indicated temperature.

[g]Condition: Same as "f" except after prestraining the specimens were aged (1/2 hour at 673°K).

TABLE 26

TENSILE PROPERTIES OF 21-6-9 CORROSION RESISTANT STEEL SHEET[a]

(Unstrained and prestrained conditions[b])

Test temperature, °F	Exposure or prestrain temperature, °F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Tensile properties			
					Ultimate strength, psi	Yield strength, 0.2% offset, psi	Elongation, percent in 2 in.	
							Total	Uniform
RT[c]	---	---	---	---	121 100	---	48.5	40.0
-110[c]	---	---	---	---	162 800	---	63.0	56.0
-320[c]	---	---	---	---	240 700	---	47.5	42.0
-423[c]	---	---	---	---	280 600	250 300	7.0	3.0
RT[d]	RT	40.0	0	0	121 100	79 000	43.0	---
RT[e]			16.0	16.0	142 300	127 500	29.0	---
RT[e]			24.0	24.0	150 900	144 100	22.5	---
RT[e]	RT	40.0	32.0	32.0	164 200	158 500	[illegible]	---
RT[d]	-110	56.0	0	0	122 800	77 700	[illegible]	---
RT[e]			16.0	15.0	145 600	110 500	[illegible]	---
RT[e]			[illegible]	33.5	174 300	141 900	17.0	---
RT[e]	-110	56.0	[illegible]	[illegible]	193 200	185 [illegible]	12.5	---
RT[d]	-320	42.0	0	0	120 100	80 [illegible]	43.0	---
RT[e]			16.0	15.0	148 900	102 600	27.0	---
RT[e]			25.0	22.0	161 500	112 600	25.5	---
RT[e]	-320	42.0	33.5	32.0	188 200	131 600	9.5	---
RT[d]	-423	3.0	0	0	119 600	75 900	46.5	---

TABLE 26. - Concluded

TENSILE PROPERTIES OF 21-6-9 CORROSION RESISTANT STEEL SHEET[a]
(Unstrained and prestrained conditions[b])

Test temperature, °F	Exposure or prestrain temperature, °F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Tensile properties			
					Ultimate strength, psi	Yield strength, 0.2% offset, psi	Elongation, percent in 2 in.	
							Total	Uniform

[a]Sheet, 0.062 inch thick.

[b]All specimens were machined from annealed material.

[c]Condition: Annealed

[d]Condition: Annealed and exposed to the indicated temperature.

[e]Condition: Annealed and prestrained at the indicated temperature.

TABLE 27

TENSILE PROPERTIES OF 21-6-9 CORROSION RESISTANT STEEL SHEET[a]

(Unstrained and prestrained conditions[b])

Test temperature, °K	Exposure or prestrain temperature, °K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Tensile properties			
					Ultimate strength, N/cm²	Yield strength, 0.2% offset, N/cm²	Elongation, percent in 5.08 cm	
							Total	Uniform
RT[c]	---	---	---	---	83 500	---	48.5	40.0
194[c]	---	---	---	---	112 300	---	63.0	56.0
78[c]	---	---	---	---	166 000	---	47.5	42.0
20[c]	---	---	---	---	193 500	172 600	7.0	3.0
RT[d]	RT	40.0	0	0	83 500	54 500	43.0	---
RT[e]			16.0	16.0	98 100	87 900	29.0	---
RT[e]			24.0	24.0	104 000	99 400	22.5	---
RT[e]	RT	40.0	32.0	32.0	113 200	109 300	16.5	---
RT[d]	194	56.0	0	0	84 700	53 600	50.0	---
RT[e]			16.0	15.0	100 400	76 200	33.0	---
RT[e]			33.5	33.5	120 200	97 800	17.0	---
RT[e]	194	56.0	45.0	45.0	133 200	127 800	12.5	---
RT[d]	78	42.0	0	0	82 800	55 200	43.0	---
RT[e]			16.0	15.0	102 700	70 900	27.0	---
RT[e]			25.0	22.0	111 400	77 600	25.5	---
RT[e]	78	42.0	33.5	32.0	129 800	90 700	9.5	---
RT[d]	20	3.0	0	0	82 400	52 400	46.5	---

TABLE 27. - Concluded

TENSILE PROPERTIES OF 21-6-9 CORROSION RESISTANT STEEL SHEET[a]
(Unstrained and prestrained conditions[b])

Test temperature, °K	Exposure or prestrain temperature, °K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Tensile properties			
					Ultimate strength, N/cm^2	Yield strength, 0.2% offset, N/cm^2	Elongation, percent in 5.08 cm	
							Total	Uniform

[a]Sheet, 0.157 cm thick.

[b]All specimens were machined from annealed material.

[c]Condition: Annealed.

[d]Condition: Annealed and exposed to the indicated temperature.

[e]Condition: Annealed and prestrained at the indicated temperature.

TABLE 28

TENSILE PROPERTIES OF 5Al-2.5 Sn ELI TITANIUM ALLOY SHEET[a]

(Unstrained and prestrained conditions[b])

Test temperature, °F	Exposure or prestrain temperature, °F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Tensile properties: Ultimate strength, psi	Tensile properties: Yield strength, 0.2% offset, psi	Tensile properties: Elongation, percent in 2 in.: Total	Tensile properties: Elongation, percent in 2 in.: Uniform
RT[c]	---	---	---	---	114 600	100 600	18.0	10.0
-110[c]	---	---	---	---	133 400	128 400	16.0	10.0
-320[c]	---	---	---	---	186 000	177 300	19.0	15.5
-423[c]	---	---	---	---	231 600	211 600	14.0	13.0
RT[d]	RT	10.0	0	0	110 500	103 800	19.0	---
RT[e]			4.0	4.0	121 900	118 900	13.5	---
RT[e]			6.0	6.0	122 500	119 600	14.0	---
RT[e]	RT	10.0	8.0	8.5	124 100	121 900	13.5	---
RT[d]	-110	[illegible]	0	0	111 700	104 600	[illegible]	---
RT[e]			4.0	4.5	122 800	120 700	[illegible]	---
RT[e]			6.0	6.0	122 600	119 400	[illegible]	---
RT[e]	-110	[illegible]	8.0	8.5	126 400	122 800	[illegible]	
RT[d]	-320	15.3	0	0	112 700	105 200	22.0	---
RT[e]			[illegible]	4.5	123 100	[illegible]	[illegible]	---
RT[e]			[illegible]	[illegible]	128 500	[illegible]	[illegible]	---
RT[e]	-320	[illegible]	12.5	[illegible]	132 400	126 900	7.0	---
RT[d]	-423	13.0	0	0	114 300	106 800	18.0	---
RT[e]			[illegible]	4.5	122 900	107 800	16.0	---
RT[e]			8.0	8.0	129 500	112 800	13.5	---
RT[e]	-423	13.0	10.5	12.0	137 000	112 400	8.0	---

TABLE 28. - Concluded

TENSILE PROPERTIES OF 5Al-2.5 Sn ELI TITANIUM ALLOY SHEET[a]
(Unstrained and prestrained conditions[b])

Test temperature, °F	Exposure or prestrain temperature, °F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Tensile properties			
					Ultimate strength, psi	Yield strength, 0.2% offset, psi	Elongation, percent in 2 in.	
							Total	Uniform

[a]Sheet, 0.071 inch thick.

[b]All specimens were machined from annealed material.

[c]Condition: Annealed.

[d]Condition: Annealed and exposed to the indicated temperature.

[e]Condition: Annealed and prestrained at the indicated temperature.

TABLE 29

TENSILE PROPERTIES OF 5Al-2.5 Sn ELI TITANIUM ALLOY SHEET[a]

(Unstrained and prestrained conditions[b])

Test temperature, °K	Exposure or prestrain temperature, °K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Tensile properties: Ultimate strength, N/cm²	Tensile properties: Yield strength, 0.2% offset, N/cm²	Elongation, percent in 5.08 cm: Total	Elongation, percent in 5.08 cm: Uniform
RT[c]	---	---	---	---	79 000	69 400	18.0	10.0
194[c]	---	---	---	---	92 000	88 500	16.0	10.0
78[c]	---	---	---	---	128 000	122 200	19.0	15.5
20[c]	---	---	---	---	159 700	145 900	14.0	13.0
RT[d]	RT	10.0	0	0	76 200	71 600	19.0	---
RT[e]			4.0	4.0	84 100	82 000	13.5	---
RT[e]			6.0	6.0	84 500	82 500	14.0	---
RT[e]	RT	10.0	8.0	8.5	85 600	84 100	13.5	---
RT[d]	194	10.0	0	0	77 000	72 100	21.5	---
RT[e]			4.0	4.5	84 700	83 200	14.0	---
RT[e]			6.0	6.0	84 500	82 300	15.5	---
RT[e]	194	10.0	8.0	8.5	87 200	84 700	13.0	---
RT[d]	78	15.5	0	0	77 700	72 500	22.0	---
RT[e]			4.0	4.5	84 900	84 800	14.5	---
RT[e]			9.5	9.5	88 600	84 800	8.5	---
RT[e]	78	15.5	12.5	12.0	91 300	87 400	7.0	---
RT[d]	20	13.0	0	0	78 800	73 600	18.0	---
RT[e]			4.5	4.5	84 700	74 300	16.0	---
RT[e]			8.0	8.0	89 300	77 800	13.5	---
RT[e]	20	13.0	10.5	12.0	94 500	77 500	8.0	---

TABLE 29. - Concluded

TENSILE PROPERTIES OF 5Al-2.5 Sn ELI TITANIUM ALLOY SHEET[a]

(Unstrained and prestrained conditions[b])

Test temperature, °K	Exposure or prestrain temperature, °K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Tensile properties			
					Ultimate strength, N/cm^2	Yield strength, 0.2% offset, N/cm^2	Elongation, percent in 5.08 cm	
							Total	Uniform

[a]Sheet, 0.180 cm. thick.

[b]All specimens were machined from annealed material.

[c]Condition: Annealed.

[d]Condition: Annealed and exposed to the indicated temperature.

[e]Condition: Annealed and prestrained at the indicated temperature.

TABLE 30

TENSILE PROPERTIES OF 6Aℓ-4V ELI TITANIUM ALLOY SHEET[a]

(Unstrained and prestrained conditions[b])

Test temperature, °F	Exposure or prestrain temperature, °F	Uniform strain capability at temperature, percent in 2 in.	Target prestrain, percent in 2 in.	Measured prestrain, percent in 2 in.	Tensile properties			
					Ultimate strength, psi	Yield strength, 0.2% offset, psi	Elongation, percent in 2 in.	
							Total	Uniform
RT[c]	---	---	---	---	144 700	126 600	11.0	7.0
-110[c]	---	---	---	---	167 500	156 500	10.5	5.0
-320[c]	---	---	---	---	221 800	208 500	10.0	3.5
-423[c]	---	---	---	---	267 700	246 200	9.0	9.0
RT[d]	RT	7.0	0	0	144 700	126 600	11.0	---
RT[e]			0	0	150 700	139 000	11.5	---
RT[f]			5.0	7.0	158 900	155 700	11.5	---
RT[g]	RT	7.0	5.0	7.0	153 400	144 200	8.5	---
RT[d]	-110	5.0	0	0	144 100	126 100	11.5	---
RT[e]			0	0	145 900	136 700	12.5	---
RT[f]			3.0	2.5	156 100	153 300	4.0	---
RT[g]			3.0	2.5	157 700	155 900	10.0	---
RT[f]			6.5	6.5	171 500	171 500	3.0	---
RT[g]	-110	5.0	6.5	6.5	147 900	144 100	9.5	---

[a]Sheet, 0.071 inch thick.

[b]All specimens machined from solution treated material.

[c]Condition: Solution treated.

[d]Condition: Solution treated and exposed to the indicated temperature.

[e]Condition: Same as "d" except after exposure to temperature the specimens were aged (4 hours at 1000°F.)

[f]Condition: Solution treated and prestrained at the indicated temperature.

[g]Condition: Same as "f" except after prestraining the specimens were aged (4 hours at 1000°F.)

TABLE 31

TENSILE PROPERTIES OF 6Al-4V ELI TITANIUM ALLOY SHEET[a]

(Unstrained and prestrained conditions[b])

Test temperature, °K	Exposure or prestrain temperature, °K	Uniform strain capability at temperature, percent in 5.08 cm	Target prestrain, percent in 5.08 cm	Measured prestrain, percent in 5.08 cm	Tensile properties			
					Ultimate strength, N/cm^2	Yield strength, 0.2% offset, N/cm^2	Elongation, percent in 5.08 cm	
							Total	Uniform
RT[c]	---	---	---	---	99 800	87 300	11.0	7.0
194[c]	---	---	---	---	115 500	107 900	10.5	5.0
77[c]	---	---	---	---	152 900	143 800	10.0	3.5
20[c]	---	---	---	---	184 600	169 800	9.0	9.0
RT[d]	RT	7.0	0	0	99 800	87 300	11.0	---
RT[e]			0	0	103 900	95 800	11.5	---
RT[f]			5.0	7.0	109 600	107 400	11.5	---
RT[g]	RT	7.0	5.0	7.0	105 800	99 400	8.5	---
RT[d]	194	5.0	0	0	93 400	86 900	11.5	---
RT[e]			0	0	100 500	94 300	12.5	---
RT[f]			3.0	2.5	107 600	105 700	4.0	---
RT[g]			3.0	2.5	108 700	107 500	10.0	---
RT[f]			6.5	6.5	118 200	118 200	3.0	---
RT[g]	194	5.0	6.5	6.5	102 000	99 400	9.5	---

[a]Sheet, 0.180 cm thick.

[b]All specimens machined from solution treated material.

[c]Condition: Solution treated.

[d]Condition: Solution treated and exposed to the indicated temperature.

[e]Condition: Same as "d" except after exposure to temperature the specimens were aged (4 hours at 812°K.)

[f]Condition: Solution treated and prestrained at the indicated temperature.

[g]Condition: Same as "f" except after prestraining the specimens were aged (4 hours at 812°K.)

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